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Volume 30 Number 7

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JULY, 1946

THE GEOLOGICAL ATTACK[1]

MONROE G. CHENEY[2]
Coleman, Texas

The critical demands of the recent war have demonstrated anew the great importance and innumerable applications of geology. It is my purpose in this address to emphasize first, the fundamental character of this science and its great potential usefulness to humanity; secondly, that geology has given and gained much in its service to the petroleum industry, but much more can be done for this and other industries through greater use and further development of this science.

That the study of this earth is fundamental to the enjoyment thereof is self-evident. However this truism seems much neglected, even in our schools. Man strives to understand his origin, exercise control over his environment, and shape a better future for his race. The struggle for self-support and the pursuit of knowledge and happiness lead most naturally toward investigation of the resources, life and history of this planet. Thus geology, the science of the earth and its past inhabitants, should be recognized as supremely fundamental to human welfare, action, and thought. It is a basic science which aids in the attack and solution of a great variety of man's most important problems.

If the problem is that of a sound philosophy of life, the evidence of progression rather than retrogression during the past billion years gives direction and encouragement. The obvious record in the rocks that many long-enduring seaways have been transformed to majestic mountain ranges brings deep realization of limitless time and energy. The great variety, quantity, and wide distribution of natural resources bring an appreciation of the abundance of our earth. The survival and co-existence of innumerable life forms, great and small, according to fitness and adaptability, set a pattern not only for the individual but for national development and international relations. Man's progress appears more impressive

[1] Presidential address, thirty-first annual meeting, Chicago, April 2, 1946.

[2] President, Anzac Oil Corporation.

than his failures and foibles when viewed in the light of a comparatively recent emergence toward civilization. Guided by this perspective the geologist finds high purpose and zest in living. He continues to seek and to find.

Wallace Pratt used the incisive epigram, "Geology Is a Way of Life" as the title of his response when he received the first Sidney Powers Memorial Award at our annual meeting of the Association last year. Undoubtedly, an understanding of the principles of geology does inspire a way of life, a way of progress and of service, a deeper desire "to do justice, love mercy and walk humbly" during our brief sojourn on earth.

GEOLOGY AND THE WAR

The world has just emerged from the most destructive of all human conflicts. We are very proud of the great contributions our science has made toward the winning of that war. A country and its armed forces lacking adequate petroleum supplies and other essential minerals are soon vanquished. Most of the enormous quantities of minerals, which brought quick victory when mobilized, had been discovered under the guidance of a few thousand specialists trained in earth sciences. In many instances the successful attack of enemy positions and quick utilization of newly conquered territory depended on the knowledge, skill, and aptitude of geologists. It is very doubtful if a greater national service has been rendered by so few specialists in any other field. We pay special tribute to those who sacrificed all to the common cause, some of whom may now rest beneath a foreign soil or wear an ocean as a shroud.

Our high profession offers equally great service toward the prevention of war. The well-being of a nation, as of an individual, depends in large measure on how it develops and uses its mental and physical heritage. The recent aggressor nations chose to squander their human and physical resources in warfare. Surely greater gain would have come had the same energy been directed toward the discovery and development of unused natural resources and normal economic activities. Both the excuse and the incentive for aggression (by so-called "have-not" nations) should diminish when and where geology and other sciences are used more fully for both cultural and economic advancement.

GEOLOGY AND THE PETROLEUM INDUSTRY

Our present interest is more directly concerned with the many important applications of geology to the problems of the petroleum industry. The scientific attack is relatively new in human experience and even more so in the discovery and development of oil fields. The past record is good, but doubtless represents only a fair beginning. Geological and geophysical techniques of increasing complexity have served to keep discoveries of oil sufficiently large not only to meet greatly expanding demands but to maintain proved reserves about 14 times the current annual rate of consumption in the United States. Interest on investment,

ad valorem taxes and economic uncertainties appear to have generally established this much reserve as a normal supply for the industry. However, this 14-year underground stockpile now appears inadequate because better engineering practices in many of our major oil fields prescribe that only three to five per cent of the ultimate production should be withdrawn each year. Thus, annual discoveries in the United States in excess of current production rate of 1,700,000,000 barrels are needed.

Fortunately, as pointed out last year by President Cram, the general stratigraphic and structural conditions are such that the hunting ground for oil in the United States includes 1,600,000 square miles and a still larger number of cubic miles of sedimentary rocks within reach of the drill. The fifty billion barrels so far discovered have been concentrated on less than 10,000 square miles. Given favorable operating conditions, it seems certain that the high discovery rate essential to national security and welfare can be maintained for many years.

Aside from the requisite healthy economic influences, it seems obvious that there should be:

1. More geological data;
2. More critical use of geological data;
3. More fundamental research;
4. More application of geology to the problems of development and recovery.

MORE GEOLOGICAL DATA

The amount of geological data useful to petroleum geologists seems quite as limitless as geologic time and stellar space. In the United States alone an area of nearly 2,000,000 square miles and a rock column of different ages having aggregate thickness of at least 200,000 feet require not merely general study but detailed examination and the systematic compilation and analysis of data. The magnitude of the task is the more impressive when one considers not only these vast areas and great rock volumes but the many lateral and vertical variations therein. Different sedimentary materials, environmental conditions, and organic and fossil content have produced complex problems beyond number. Subsequent to deposition numerous structural, chemical, and physical modifications have taken place.

A knowledge of regional relationships is essential but this must be supplemented by very detailed studies in search of particular localities having conditions favorable to oil and gas accumulation. Normal values for many types of information are needed as an aid in the selection of the most promising locations for drilling. Some 25,000 wells drilled each year add new sources of geological data requiring close study by specialists in petrology, paleontology, stratigraphy, geochemistry, geophysics, and structure who have the responsibility of determining correct regional correlations, suitable classification of the rock sequences, isopach and paleogeologic maps, faunal and floral zones, facies changes, vertical and lateral extent of oil- and gas-bearing zones, character of reservoir rocks and

their fluids, time and place of progressive structural developments as well as the present normal strike and rate of dip for each "layer of geology."

For lack of adequate personnel, much useful geological work remains undone.

MORE CRITICAL USE OF GEOLOGICAL DATA

Not only is there need of a greater store of geological information but also of well established criteria by which such data may be used more effectively. Much progress has been made toward the development and use of methods for recognition of favorable regions, localities, and well locations, but more definite analysis is no doubt possible as well as highly desirable.

In most oil provinces some structures are found to be productive while others seemingly as promising fail to yield commercial production. In seeking an explanation, the Mid-Continent region affords advantages as a testing ground because of moderate structural folding, many dependable stratigraphic controls, limited extent of reservoirs in some producing zones, and extensive drilling both on and off the upfolded areas. In this region a large proportion of producing structures are characterized by local thinning in the 2,000 feet or less of strata next above the productive zone, whereas unproductive structures nearby lack this distinction. In many cases no other difference is apparent. The implications that in this region and presumably elsewhere, most of the oil and gas originated, migrated, and accumulated prior to deep burial and late folding are of such fundamental importance that further discussion and critical study of this evidence appears warranted. Even if found valid for this region some qualification will no doubt be needed for wide application. For example, the critical thickness of load may vary according to freedom of escape of fluids from the reservoir beds. In general, discrimination between folding which developed during early stages of progressive sedimentary loading and that which occurred subsequently appears to be extremely important in the search for structurally controlled oil fields. Thus the preparation and use of local and regional isopach maps revealing trends and areas of early folding becomes an essential part of petroleum geology. Such maps should aid not only in the evaluation of a local structural feature but also as a basis for analysis of conditions prevailing when oil concentrations of the stratigraphic or lithologic control type were taking place. Reflection-seismograph data should be of special help in some areas for differentiating between early and late folding.

That oil may be formed prior to deep burial is supported by investigations under Research Project 43 of the American Petroleum Institute, as reported in recent articles in the *Bulletin* and reviewed by G. M. Knebel at this meeting. The evidence at hand strongly indicates that petroleum may be produced rapidly at low pressures and temperatures from some organic materials by certain types of anerobic bacteria (43 A), and similarly during a period of a few million years by radioactive processes (43 C). Also hydrocarbons and petroleum-like substances are evidently produced as a life process by many types of organisms including

such abundant and simple forms of life as bacteria and algae (43 A and B).

The expulsion of organic solvents containing fluid hydrocarbons (actual or potential), or of discrete, sparsely disseminated globules of oil or oil films on gas bubbles, from water-saturated muds (in which nearly all of the organic source material in sediments is found) is most satisfactorily explained, in the opinion of many geologists, as being the result of compression and compaction and reduction of pore space in the muds. The accumulating overburden exerts a pressure at least twice that of the nearly equal column of fluids being expelled. Some excess sedimentary weight may be necessary to overcome resistance to movement of the fluids being expelled from capillary and subcapillary spaces of the source beds. However, reduction of pore space in argillaceous muds is known to occur in general according to the amount of compression; hence, displacement of fluids must take place roughly as the load increases, although evidently at a diminishing rate. In calcareous muds, reduction of pore space by compaction and crystallization likewise doubtless proceeds more slowly with increasing pressures and time. Thus fluid expulsion and hydraulic movements should be most active and effective during burial to depths of 1,000 to 2,000 feet during which most of the oil may have been generated and expelled from the source beds. Obviously, pressures of 1,000 to 2,000 pounds per square inch must have a very great effect on water-saturated muds having initial porosities of 50 to 80 per cent.

It seems reasonable to assume that the expelled fluids normally move in the direction of least resistance, and from the muds into the more permeable reservoir rocks above or not far below; also laterally for some distance into flanking reservoirs. Lateral fluid movements within the reservoir rocks would of course depend on permeability, continuity, and direction of easiest escape, whether updip or downdip, as the case might be, toward marginal or structural outlets or toward areas of thinnest cover. Some concentration of fluid movement should develop along early trends of folding and thinning because of less pressure there; also toward early folds and uplifts where a thinner, somewhat coarser and more fractured cover may provide some increased facility of vertical escape.

In any case, whatever oil and gas became entrained in movement of the large amounts of expelled water would tend to accumulate under influence of bouyancy and filtering in areas of local uplift and in the higher parts of buried reservoir margins. Such other factors as variations of permeability, differences between the viscosity of oil and water, no doubt also play important roles in controlling migration and accumulation of oil. Later growth of local folds would cause progressive concentrations of oil and gas into smaller areas and deeper burial would create greater fluid pressures within the reservoir.

According to this line of reasoning, when a region changes from an area of subsidence to one of emergence, perhaps of strong mountain building, and erosion and unloading are in progress, the fluid movement would be subject to very different influences. Expulsion of fluids from source beds would cease except as caused by strong diastrophic forces. More commonly shales would re-expand

somewhat, quite possibly as a result of capillary action, as indicated by records of reduced densities of given shale bodies as they approach the surface.

Re-absorption of water from the reservoir beds may produce sub-normal reservoir or hydrostatic pressures, as has been noted in western Appalachian and other regions. Migration of oil and gas may cease entirely or be limited to small quantities escaping from some area of concentration as a result of (1) re-expansion of gas, (2) tilting of beds, or (3) possible effect of capillary forces which may become operative when the tendency is toward a deficiency rather than excess of fluids as expansion of fine-grained rocks takes place.

More complete and accurate data from wildcat tests are needed. The industry fails in many cases to make maximum use of information from dry holes. Many important oil fields have been found by discovery wells located at their margins. Doubtless many others are missed by short distances. Scientists and engineers in the oil industry helped to develop the proximity fuse. It is hoped equal success will be achieved in devising or recognizing proximity indicators or detectors of petroleum.

For example, abnormally low sulphate content of waters near oil accumulations has been observed in some oil provinces. Additional drilling at a somewhat higher position on a structure may be warranted where a wildcat failure reveals this condition. Obviously, water from prospective oil zones should be collected and analyzed more generally.

Sediments and fossils characteristic of lagoonal or brackish-water deposits may serve to encourage additional drilling basinward in search of oil accumulations in sand bars or barrier beaches. Similarly, determination of pontic and lagoonal facies may be used as a guide to further drilling where limestone reefs may serve as oil reservoirs.

As has been pointed out by others, "controlled imagination," persistent effort, and financial fortitude are also essential to successful exploration for petroleum.

MORE FUNDAMENTAL RESEARCH

The statement that the strength and vigor of a science or of an industry can be no greater than its fundamental research program is doubtless correct. It is therefore fitting that this Association should give primacy to its research program.

It seems certain that petroleum geologists can not render maximum service until the difficult problems of origin, migration, and accumulation of oil have been solved. New concepts and new methods for discovery and recovery are certain to follow when a more complete knowledge of these fundamentals is at hand.

Since we deal chiefly with marine sediments, much benefit should come from oceanographic studies. The study of Recent sediments of the Gulf of Mexico, and elsewhere as recommended by the Association's research committee, undoubtedly deserves general support.

Unexpected offshoots of research projects may be counted on to add important

results. As an example, it is quite probable that ZoBell's studies of the role of bacteria in the transformation of organic substances to petroleum will have important applications to migration and recovery problems as well as to the discovery of petroleum. His observations that bacterial action may cause release of oil from rock surfaces may lead to greatly increased recoveries through proper bacterial innoculation of oil reservoirs.

Professor Denis L. Fox, and associates, also of Scripps Institution of Oceanography, have added to our knowledge of probable source material by his studies of fossil pigments.[3,4]

Some of these natural hydrocarbons ($C^{40}H^{56}$ *et cetera*), which are formed in considerable quantities by algae and all plant life, are less digestible than most of the other organic material; hence they tend to accumulate and remain in the muds of the sea floor. In some muds sufficient quantities of these pigments are present to give a "deep green-brown, greenish orange or yellow color to appropriate organic solvents." Their quantity in some Piggot gun cores was found to be as high as one part per 100,000 by volume. In such quantity these naturally occurring hydrocarbons may be thought of as a contributing source of oil, after changes by hydrogenation or splitting of the heavy molecules. Their florescence and insolubility in water but solubility in organic solvents suggest that these more refractory hydrocarbons may add in an important way to the character and bulk of petroleum found in reservoirs associated with such muds. Curiosity concerning the source of coloring matter in organisms living in the "ocean's unlighted depths" inspired the extensive investigation of these pigmentary compounds in bottom sediments.

More fundamental research is needed to solve many problems related to petroleum discovery and recovery as well as in the everpresent questions of how, when, and why does petroleum originate, migrate, and accumulate. The answers must be applicable to a wide variation in the quality as well as the quantity of oil, the latter including concentrations in the amazing quantities of billions of barrels. It should be noted, moreover, that some of the greatest accumulations, such as in the East Texas and Athabaska regions, reveal no evidence that high pressures and temperatures were involved in the origin, or that gas was essential to the migration of the oil. Some six billion barrels of oil must have accumulated in the reservoir of the East Texas field either in spite of a marked deficiency of gas or prior to the development of pressures of about 755 pounds per square inch, this being the bubble point at time of discovery when reservoir fluids showed pressures of approximately 1,600 pounds per square inch.[5]

[3] Denis L. Fox, "Biochemical Fossils," *Science*, Vol. 100, No. 2589 (August 11, 1944), pp. 111–13.

[4] Denis L. Fox, David M. Updegraff, and G. David Novelli, "Carotenoid Pigments in the Ocean Floor," *Scripps Inst. of Oceanography, New Series No. 236, Archives of Biochemistry*, Vol. 5, No. 1 (September, 1944). 23 pp.

[5] Ben E. Lindsly, "A Study of 'Bottom Hole' Samples of East Texas Crude Oil," *U.S. Bur. Mines R. I. 3212* (May, 1933).

The small gas area in the southeastern part of the field suggests an early accumulation of free gas. It seems probable that a major portion of gas forms and migrates in advance of the formation and movement of the bulk of the oil. Doubtless the effectiveness of free gas as a cause of oil migration diminishes progressively with deeper burial because as pressure increases the gas volume would be reduced and more gas would be dissolved in the oil with which it comes into intimate contact. The dissolved gas may of course aid oil migration materially by lowering the viscosity of the oil.

Isopach studies of the Tyler basin reveal that the Eagle Ford, Austin, and Taylor rocks overlying the producing Woodbine sand change from a combined maximum thickness in the deeper part of the basin of 3,000 feet to less than 1,300 feet sixty miles farther east in the huge East Texas oil field. This comparatively moderate rate of thinning of 28 feet per mile must have created differential pressures of 27 pounds per square inch per mile (using average density of 2.2 for the weight of the overburden). Bouyancy of oil with specific gravity as low as 0.85 (34.7 A.P.I.) in a 28-foot column would be less than 2 pounds per square inch per mile, a combined effect of nearly 29 pounds per square inch per mile.

Updip extensive regional migration is indicated not only by the enormous quantity of oil in the East Texas field but by progressively heavier oils found in fields nearer the deeper part of the basin. Doubtless the heavier, more active hydrocarbons are selectively absorbed to some degree by the reservoir rock through which the oil moves.

In the Tyler basin the folds which reveal appreciable progressive structural development by thinning in the first 2,000 feet more or less of post-Woodbine strata are commonly highly productive from the Woodbine sand, whereas intervening folds revealing 2,500 feet or more of loading before developing closed structure are notably unproductive. The Kelsey anticline with 300 feet of closure in Woodbine sand and located within 12 miles of the enormous East Texas field is a classic example.[6]

More fundamental research is needed to verify or condemn the various theories which have been developed regarding origin, migration and accumulation including the compaction-hydraulic theory as reviewed above.

MORE APPLICATIONS OF GEOLOGY TO PROBLEMS OF DEVELOPMENT AND RECOVERY

Many problems of oil-field development and production should be amenable to geological attack. No doubt the field of geological engineering can be expanded materially. This is becoming more and more essential as expenditures per well increase because of deeper drilling and other factors.

[6] A. R. Denison, A. E. Oldham, and J. W. Kisling, Jr., "Structure and Stratigraphy, Kelsey Anticline, Upshur County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 6 (June, 1933), pp. 656–79.

Geologists should aid petroleum engineers in determining and forecasting the characteristics of a newly discovered oil pool. Studies of the reservoir rock itself as well as structural features and regional relationships of the producing reservoir have important bearing on determining appropriate well spacing, development and production programs. Particularly important are determinations as to whether water, dissolved gas, or gas-cap drive will predominate, how reservoir energies may be utilized most effectively, and movement of oil to the wells facilitated.

The wide difference in opinion regarding optimum spacing of oil wells needs no better illustration than two articles in the February, 1944, issue of the *Bulletin.*[7,8]

Production data for the past 5 years support Elliott's conclusion that the ultimate production from the Jones sand of the Schuler field will be about 60 per cent (20,000,000 barrels) greater as a result of unitization and return of gas to the reservoir than was indicated by the prior 3.5 years' production record. This is being accomplished after changing from 10- and 20- acre spacing of producing wells to an average of 60 acres per producing well. On the other hand, the article by Clark, Tomlinson, and Royds appears to present convincing evidence that percentage recoveries may be doubled by quadrupling the density of drilling as shown by statistical data from nine fields.[8a]

The variables involved in determining the most desirable well-spacing pattern are apparently too numerous to permit formulation of fixed rules. Many of these variables deal with such geologic subjects as the structure and characteristics and probable uniformity and continuity of the reservoir rock. Obviously such features have a bearing on forecasting the type of drive which will be operative during the period of primary production; also, on the probable need and effectiveness of pressure maintenance and secondary-recovery operations.

The evidence presented in the two papers here cited serves to emphasize that under favorable conditions efficient production-engineering practices may be advantageously substituted for close spacing of wells. Most of the data for the latter paper were derived from fields developed and produced under highly competitive conditions, prior to development of modern methods of reservoir analysis and production. The effects of several indeterminable factors were evidently ascribed solely to differences of spacing.

Comparison of yields from the Mexia-Powell fault-line fields are not conclusive because productive reservoir volumes and possible differences of connate-water content, oil shrinkage and other factors can not be definitely established.

[7] George R. Elliott, "Geologic Factors in Unitized Pressure Maintenance, Jones Sand Reservoir, Schuler Field, Arkansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28 (1944), pp. 217–30.

[8] Stuart K. Clark, C. W. Tomlinson, and J. S. Royds, "Well Spacing—Its Effect on Recoveries and Profits," *ibid.*, pp. 231–56.

[8a] For critical review of the data and conclusions presented by Clark *et al.*, see article by W. V. Vietti, J. J. Mullane, O. F. Thornton, and A. F. Van Everdingen, entitled "The Relation between Well Spacing and Recovery," *Oil and Gas Jour.*, Vol. 45, No. 4 (June 1, 1946), pp. 77–93.

The electrical as well as drillers' logs shown in Figure 5 of the report by Hill and Guthrie[9] strongly indicate that the calculations of acre-feet of pay used for the Mexia field were excessive; hence, that acre-foot yields were underestimated in this field. The reverse may be true of the much narrower Wortham field which reached its peak production within 3 months after discovery, was 95 per cent drilled up within 4 months,[10] and produced 72 per cent of its oil within the first 13 months. Under these circumstances this field may have had a lower water-oil contact, as discussed by Hill and Guthrie, hence more acre feet of pay and a lower yield per acre-foot than used in their estimates. The calculated yields are based on averages of 56.9 feet of pay thickness for the Mexia field and 24.8 feet for Wortham. It would be difficult to prove that recoveries comparing favorably with those actually obtained from Wortham could not have been achieved from one-tenth as many wells, had modern production methods been used. Admittedly other fields with 20-acre spacing, instead of 2.2 acres as in the Wortham field, are recovering close to maximum possible percentages from sandstone reservoirs no more permeable than the Woodbine reservoir at Wortham.

In the other fields reported by Clark *et al.*, the yields per acre-foot used for comparative studies make no allowances for the variations in character of reservoir, production method, or the great advantage gained by some of the earlier wells having large flow while reservoir pressures were high. Early wells in some sandstone reservoirs are apparently benefited also through better establishment of drainage areas, a factor unrelated to spacing. Evidence opposing close drilling comes from very large yields by individual wells flowing normal recovery for 80 acres or more where interference from near-by wells was absent for several years. Maintenance of relatively high oil saturation and favorable permeability to oil movement in the reservoir around the producing well may be an important advantage gained by wider spacing.[11]

In the deep Oklahoma City field the effect of date of well completions can not be neglected. The average date of completion in some quarter sections was as much as one year ahead of an adjoining quarter section. Since many of the individual wells were producing in excess of 100,000 barrels per year during the early life of the field, the lateral migration in this excellent reservoir would account for much of the unequal yields which have been attributed by Clark *et al.*, solely to differences of well spacing.

In many fields wider spacing has been used during later stages of development because of uncertainties created by reduced pressures or marginal drilling. Lower

[9] H. B. Hill and R. K. Guthrie, "Analysis of Oil Production in the Near-Depleted Mexia-Powell Fault-Line Fields of Texas," *U. S. Bur. Mines R. I. 3712* (1943).

[10] Frederic H. Lahee, "Oil and Gas Fields of the Mexia and Tehuacana Fault Zones, Texas," *Structure of Typical American Oil Fields*, Vol. 1, Amer. Assoc. Petrol. Geol. (1929), p. 321.

[11] M. C. Leverett and W. B. Lewis, "Steady Flow of Gas-Oil-Water Mixtures through Unconsolidated Sands," *Amer. Inst. Min. Met. Eng. Tech. Pub. 1206* (May, 1940), Fig. 9.

initial production, more rapid decline, and subnormal yields are to be expected, regardless of spacing in such cases.

Asphaltic residues in southern Oklahoma oils, such as found in the Hewitt and Healdton fields, have no doubt affected operating efficiency of the wells in these early, inefficiently produced, fields.[12]

Perhaps the only general rule which can be formulated regarding well spacing is that all geological, engineering, and economic factors should be carefully studied in each new pool, whereupon a conservative drilling and spacing program should be adopted with knowledge that additional wells can be drilled if found necessary for high percentage recovery, special attention being directed meanwhile to the use of the most efficient engineering practices.

The responsibilities of the geologist do not end with the selection of a favorable wildcat block and drilling location. Recognition of pay zones in drilling wells, reservoir characteristics, completion and production practices, and of course the structural features of the producing reservoir should receive his closest attention.

Thus, as previously stated, geology is a fundamental science which has numerous applications. Obviously, many of the important problems of the oil industry as well as in other fields of human endeavor and relationship, may be solved by geological attack.

[12] T. E. Swigart and F. X. Schwarzenbek, "Petroleum Engineering in the Hewitt Oil Field, Oklahoma," *U. S. Bur. Mines* (January, 1921), p. 96.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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EXPANDING ACTIVITIES OF PALEONTOLOGISTS[1]

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ABSTRACT

The original employment of economic paleontologists as microscopists engaged in the routine examination of well samples has had several unfavorable aspects both in the laboratory and in the field. Under more recent practices this condition is being improved, and paleontologists' work is assuming wider scope. These modifications result from a growing recognition of capabilities possessed by members of this group which qualify them for successful activities in the closely related fields of applied stratigraphy and subsurface geology, including exploration, and research. Their qualifications are based on broad fundamental training and intimate experience with sedimentary rocks. Numerous recent accomplishments furnish evidence of the broader scope of paleontologists' current activities. In order that the potential services of paleontologists may be better utilized in the field as well as in the laboratory, it is desirable that improved facilities be provided for carrying on their work. Greater personal effort toward development of the expanding opportunities and realization of their wider responsibilities on the part of paleontologists as individuals promises an interesting future for them.

INTRODUCTION

The subject matter of economic paleontology has been considered in the addresses by presidents of the S. E. P. M. many times in the past. The history of the practical use of fossils has been traced from early antiquity; various stages of its application have been followed through the years, and the science has been shown to merit a permanent place of usefulness in the oil industry. All of these steps in the advancement of the profession are important, and thoroughly worthwhile, but they have been treated impersonally, and rarely has anyone dwelt upon the activities of paleontologists as individuals. The personal issues involved merit consideration, and it is the purpose of this discourse to present a realistic view of some of the everyday functions of the people who use the science, and to indicate the desirability of expanding the applications of their talents.

ROUTINE ACTIVITIES

It is problematic if all petroleum geologists, not to mention academicians, have full conception of what paleontologists actually do in carrying on their duties. Obviously everybody knows they study fossils; that they spend much time pouring over a microscope in the laboratory. But is it generally known what they observe other than fossils, and where they work besides in the laboratory? Since they are scientists, at least of a sort, it is a natural conclusion that they carry on research. But what is the nature of their research and how is it accomplished? The answers to these questions are found by watching paleontologists in their laboratories, by following them to the field, by looking at their research efforts.

Answer to the first question comes from the well known fact that paleontolo-

[1] Address of the president of the Society of Economic Paleontologists and Mineralogists before the joint annual meeting of the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, and the Society of Exploration Geophysicists. Presented by permission of Magnolia Petroleum Company.

[2] Geologist, Magnolia Petroleum Company.

gists examine well cuttings. In so doing they observe not only fossils, but everything that goes to make up the section of rock drilled. Minerals are recognized, along with their color, crystalline character, grain size, angularity, sorting. Lithology is noted, including color, texture, bedding, degree of induration, porosity, oil saturation. Conditions of sedimentation are interpreted, furnishing evidence of shore lines, of basins, of stratigraphic traps. All of this varied information must be presented in practical, readily applied form. Usually it appears as an elaborate plotted log, or as a lengthy, descriptive "paleontological report." This formal presentation of their findings generally marks the end of the paleontologists' duties, with deductions and prognostications being carried on in another department. In the last few years a departure from these methods has developed, and the activities of paleontologists are being broadened in many organizations.

As for work in the field, presumably all paleontologists make occasional excursions for the purpose of collecting samples, measuring sections, observing stratigraphy, and a welcome relaxation this is from continuous laboratory duty. Checking or "sitting on" a drilling well occasionally affords most laboratory workers a gratifying change of routine. Unfortunately, however, the ideal of alternating laboratory and field work is not often realized, and field men must spend protracted periods away from home and office. Frequently for weeks on end they are far removed from any of the comforts and conveniences of their headquarters. Their microscopes may stand on an upended block of heavy rig timber, an empty nail keg, or an oil barrel, while an August Gulf Coast sun beams down on their bare heads. In mid-January they seek refuge from winter weather in a steel "dog house," by a makeshift oil-can stove, under a dingy rig light, or they may strive to look through a microscope placed on the vibrating, jolting, jarring work bench behind the driller's derrick floor shelter. Only slightly better conditions are available in their automobiles, where they hold the microscope on their knees, and illuminate it with a small lamp connected to the car battery. In some instances "well sitters" enjoy the hospitality of the drilling superintendent, or "tool pusher," who provides them quarters in his portable bunk-house. This affords a measure of physical relief, but facilities for sample examination are entirely inadequate. Working under these crude conditions, with wet, muddy samples, they struggle frantically to find some shred of evidence that wells are running high, that faults have been crossed, that coring points for anticipated oil horizons are only a few feet deeper. It seems miraculous that the men on the wells so seldom fail to get this extremely important information.

During recent years, except in the period of war shortages, there has been a growing practice of furnishing paleontologists a portable laboratory for use in the field. This usually is a small house trailer, equipped with connections for running water and a sink for washing samples, a hot plate for drying them, a microscope table and desk, cabinets for storage of equipment, good illumination, a heater, an electric fan, and a comfortable bunk for physical recuperation when opportunity is presented. Other technical service crews, such as mud engineers, core

analysis men, and certain logging crews, commonly are thus equipped, but the practice has not yet become general for geologists and paleontologists. These facilities when placed at the disposal of trustworthy personnel must surely secure results of sufficiently greater accuracy and dependability to more than offset the comparatively small investment required.

Looking at papers published by economic paleontologists, it is evident that they are neither very numerous nor very comprehensive. Mostly they are systematic descriptions of faunas from restricted zones of sediments. Excellent contributions they are, and extremely useful to the practical worker, but their scope necessarily is limited. Why is this? Principally because, as was pointed out in the discussion of laboratory workers, the range of their experience is cut off at the factual level. Even though their contributions would be of general value to all who make use of paleontological studies, little opportunity is available for obtaining results suitable to be published. There is no doubt that much information valuable to the geological profession, and to the petroleum industry as a whole, is lost because this phase of the paleontologists' potential contribution to science is so generally neglected.

POTENTIALITIES OF PALEONTOLOGISTS

That there is latent ability in the rank and file of paleontologists is evidenced by the occasional appearance of brilliant and comprehensive papers by individuals who have overcome the handicaps of their jobs by burning the midnight oil, and by the significant, but much less frequent, promotion to outstanding positions of those persons whose accomplishments have risen to the level of recognition because of their persistent energy, and despite limiting circumstances. It stands to reason that in a group of workers who, paraphrasing the words of former President Driver,[3] almost without exception are graduate geologists many of whom hold advanced degrees, and who are favored with facilities and training to see more in rocks than others not so equipped, there is much ability which should receive wider utilization.

SUBSURFACE GEOLOGY

The rapid spread of electrical well-logging has furnished petroleum geologists a tool particularly valuable for subsurface interpretations. It came into practical use just as economic paleontology reached its zenith. Recently there has been added the method of logging well sections by radioactivity, which, because it shows the presence of fluid in the rocks,[4] has immediately practical applications. Time logs have also proved useful. There can be no doubt that these auto-

[3] Herschel L. Driver, "Economic Paleontologists and Mineralogists, an Appraisal," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 7 (July, 1943), pp. 938–47.

[4] Oil and water can not be distinguished at present, but the problem of differentiating them is under intensive study by geophysical research men, and holds promise of being solved.

matic methods of recording subsurface information are displacing in large measure the routine examination of well samples. This, however, does not mean sample work is on the way out. On the contrary, these methods are supplementary, each contributing some information not supplied by the other. Each is a tool which accomplishes a particular purpose. Invariably the accurate interpretation of stratigraphy recorded by electrical, time, and radioactivity logs from *wildcat* wells necessitates that they be compared with sample logs and paleontological markers. And who, by virtue of both training and experience, is better equipped to make these interpretations than paleontologists? Because of their intimate knowledge of lithologic changes, textural variations, and sedimentary trends they are able to make log correlations with a high degree of accuracy. When correlations have been established, the major task of subsurface mapping has been accomplished. Calculating data and contouring are largely mechanical, while construction of cross sections is principally a matter of drafting.

STRATIGRAPHY

Stratigraphy has been defined as the sequence of strata, stemming from the early work of Wm. Smith, who first appreciated the practical need of establishing the correct order in which layers of rock occur. Simple though its origin may have been, the study actually is quite complex and involves some phases of nearly all geological fields. Paleontology is a fundamental component of stratigraphy, as are mineralogy, petrography, sedimentation, and even tectonics. The principal objective of "straight" economic paleontology, as carried on by oil companies is the establishment of sequence of strata in wells. It follows, therefore, that the work of the economic paleontologists is not pure paleontology, but stratigraphy. Carey Croneis,[5] in his presidential address in 1941, called it "microstratigraphy."[6] The appropriateness of this terminology is quite evident when one realizes that in examining well cuttings the microscopists find fossils in not more than twenty-five per cent of the samples, as a rough average, and that they spend much more of their time observing physical criteria which enable them to establish the correct order in which sedimentary beds have been deposited. With the detailed information thus gained of the mechanical aspects of sedimentation, as well as knowledge of the organic processes of rock formation, it is clearly evident that paleontologists are eminently qualified to contribute much to the search for stratigraphic traps. Of late some derision has been directed at the emphasis being placed on this type of potential reservoirs, because it is contended they are so difficult to discover. This attitude is justified when considered from the viewpoint of the surface geologist, or the structural expert. The direct methods are of little avail in this task of finding stratigraphic traps, but the less spectacular, indirect

[5] Carey Croneis, ' Micropaleontology—Past and Future," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 7 (July, 1941), pp. 1208–55.

[6] This suggests the possible desirability of substituting the term "Stratigraphers" for "Mineralogists" in the Society's name.

approach of the sample workers holds much promise of satisfactory discoveries in this field. "Exploratory thinking," when aptly employed by the "microstratigraphers" can scarcely fail to locate numerous old shore lines, "pinch-outs," overlaps, and areas of favorable sedimentation.

Evidence of this type of investigation is furnished by the discovery of subsurface Jurassic in the Gulf Coastal Plain. No rocks of this age appear anywhere at the surface in the region, and before deep drilling there was nothing but philosophical reasoning to indicate their presence at depth. In fact it is evident that their occurrence was unsuspected before the discovery of salt in the Smackover field in 1932, and it was not until 1939 that Hazzard[7] indicated the possibility of Jurassic age for the pre-Comanche formations which were generally known in wells of southern Arkansas and northern Louisiana. This suggestion was based on a tentative correlation of these strata with rocks identified by Burckhardt[8] as Jurassic in the Mexican Gulf's San Ambrosia well No. 1, about 52 kilometers southwest of Laredo. About a year later Imlay[9] obtained definite paleontological evidence from cores that the South Arkansas formations below the known Lower Cretaceous were Jurassic. Since that time these sediments have been found in wells as far east as Alabama, and their presence is predicted in a subsurface belt extending all the way around the inner border of the Gulf Coastal Plain. They probably occur throughout the Gulf Embayment, but for the most part this is beyond verification because of the great thickness of overlying sediments. This entire subject has been thoroughly discussed by Imlay[10] who generously credits the petroleum geologists, including numerous paleontologists, with the contribution of most significant data used in the study. In his own words[11] "The results of these studies are presented . . . as a demonstration of the value of paleontological and regional stratigraphic studies during the progress of oil exploration." Obviously the subsurface data were obtained from cuttings and cores which passed under the microscopes of sample workers or economic paleontologists.

Another contribution to subsurface stratigraphy based entirely on "paleontology" or the examination of well samples, is the discovery of Kiamichi beds in southwest Texas. Nowhere along the Cretaceous outcrops south of Coryell County, either in the Balcones escarpment or on the southern Edwards Plateau, are there any known exposures of Kiamichi, although it has good surface expres-

[7] Roy T. Hazzard, "Notes on the Comanche and Pre-Comanche (?) Mesozoic Formations of the Ark-La-Tex Area, and a Suggested Correlation with Northern Mexico," *Guide Book of Shreveport Geological Society*, 14th Annual Field Trip (1939), pp. 155–78.

[8] Burckhardt and Mullerried, "Neue Funde in Jura und Kreide Ost und Sud Mexicos," *Ecologae Geol. Helvetia*, Vol. 29, No. 2 (1936), p. 319.

[9] Ralph W. Imlay, "Lower Cretaceous and Jurassic Formations of Southern Arkansas and Their Oil and Gas Possibilities," *Arkansas Geol. Survey Inform. Cir. 12* (1940), pp. 7–27.

[10] Ralph W. Imlay, "Jurassic Formations of Gulf Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 11 (November, 1943), pp. 1407–1533.

[11] *Ibid.*, p. 1410.

sion in north and west Texas. The formation seems to be completely overlapped in the Coastal Plain. The presence of Kiamichi beds was first suspected when Hedwig Kniker, examining the Maryland's McKnight well in Dimmit County reported a 300-foot section of black shale, brown limestone, and anhydrite between typical Georgetown and Edwards limestones. The section had been penetrated previously in Maverick County, but it was not recognized there until wells were drilled subsequently to the completion of the Maryland's McKnight. Later it was encountered in a number of wells drilled in the Nueces embayment, and the approximate line along which it "pinches out" has been traced across southern Val Verde, Kinney, and Uvalde counties. Significantly the formation is absent in all wells over the San Marcos arch, and for some distance on either side. That this typical example of a "pinch-out" has possibilities as an oil reservoir is evident, but localization of favorable areas must await additional refined work.

OPPORTUNITIES IN RESEARCH

In the field of research paleontologists are qualified to make contributions to a constantly expanding realm of topics. The current report of the A.A.P.G. research committee lists not less than sixteen projects, from a total of thirty-two, which come within the sphere of economic paleontology. Foremost among these are the oceanographic investigations, both those already under way, and the newly proposed projects. The northern Gulf of Mexico studies and the Gulf of California investigations offer particularly fruitful opportunities for employment of paleontological talent. Studies of the faunas, sediments, and physical conditions of these areas of present deposition hold promise of revealing much which will be useful in interpreting stratigraphy on the contiguous land. In fact a great deal of information already has been assembled which, when it can be made generally available, will prove most interesting to economic stratigraphers. The well known principal of uniformitarianism advanced by Lyell that the present is key to the past offers no more fertile field of application than in the interpretation of Gulf Coast stratigraphy. There can be little doubt that at many times in the past conditions have prevailed which closely resemble those now occurring at one place or another along the submerged Gulfward border of the Continent. Add to these very comprehensive problems the numerous more restricted, but none the less important, investigations of fossils, sediments, and ecology that may be made elsewhere in the various oil provinces of the world, and it is apparent that there is ample material to keep paleontologists busy in the field of research for many years to come.

CONCLUSION

In conclusion, let it not be said that economic paleontologists are growing restive, that they are resentful, or that they have become egotistical. Close observation shows that on the whole they are a quiet, contented, modest group,

more inclined to accept their lot than to show dissatisfaction. This very complacency constitutes a handicap and is partial justification for presenting the views expressed herein. If a greater appreciation of opportunities and a more general utilization of abilities may be stimulated thereby this effort will be well spent. Realization of their potentialities by individuals and recognition of their talents by the petroleum industry portends ever widening fields of activity and a promising future for paleontologists.

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PUBLICATION OF GEOPHYSICAL CASE HISTORIES[1]

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As an introduction to the subject, I wish to review certain aspects pertaining to exploration and the history of the Society of Exploration Geophysicists.

Prior to about 1925 economic geologists found many well marked virgin surface structures in North America. Predictions were made, and later confirmed, as to structural uplift and closure; and in numerous cases, predictions as to probable oil production were also confirmed. Shortly thereafter, in those areas which had been mapped geologically, using E. DeGolyer's simile, the more apparent big fish had been caught in the surface geology net and new arts were needed to seine deeper.

In an overlapping period exploration geophysics was started in the United States, torsion-balance gravity work in 1922, and refraction seismograph in 1923. Many domal uplifts were quickly found, most of these having little or no apparent expression in the surface beds. The majority of these are now producing oil or gas. The torsion balance has accounted for many shallow, medium-depth, and some deep salt domes. Mainly due to greater speed, gravimeters have almost completely replaced torsion balances, and numerous oil fields owe their discovery either fully or partially, to interpretation of anomalies shown by this method. Through refraction-seismograph work, predictions have been made as to the location and depth of shallow and medium-depth salt domes; and drilling has confirmed the depth and extent of the cap rock or salt. Later, in the case of reflection seismograph, predictions made as to amount and area of closure, and as to depth of producing zones, were verified by drilling. Magnetometer results have indicated some igneous plugs and other anomalies directly, and helped to delineate the regional basement trends. In addition, progress is being made in geochemical and electrical prospecting methods, and these hold promise for the future, though they have not approached the economic state of the other methods.

Since the founding of S.E.G. in 1930, one of the main themes of our retiring presidents has been that of encouraging co-operation between geophysicists and geologists in our duty of finding new oil reserves. Happily, co-operation has been attained.

Full co-operation is more essential now than ever before because of interpretation, or attempted interpretation, of the pinchout and lenticular type of stratigraphic traps, closures associated with faults, and overthrusts. Now, maximum ingenuity must be used to discover new arts, as well as to improve present methods suitable for such exploration. It is considered possible but not probable

[1] Presidential address, Society of Exploration Geophysicists, delivered in Chicago, April 2, 1946, before joint annual meeting of this Society, the American Association of Petroleum Geologists, and the Society of Economic Paleontologists and Mineralogists.

[2] Director, geophysical exploration, Magnolia Petroleum Company.

that novel exploration methods will be developed as a result of wartime inventions.

There are two principal reasons for the formation, present existence, and future being of the Society of Exploration Geophysicists. The first, mainly intangible, is the value one receives from the joint annual meetings. By that is meant information acquired from manuscripts that are read, from accompanying discussions, and in personal contacts with old friends and new. The second reason, a tangible one, is our journal *Geophysics*. Neither the annual meetings nor the Society would have flourished without the other. Few exploration geophysicists feel the natural urge to write manuscripts unless, as a result of the extra study and preparation, they are given the privilege of delivering the paper orally. In that manner the author himself receives additional benefits from the discussion period that follows. The same holds true for A.A.P.G. and S.E.P.M.

The majority of the manuscripts published in the past by S.E.G. members relate to pure research, to the results of applied research and development as concerns instrumentation, to field techniques, and to office interpretational methods. This is the natural course of publication on the geophysical methods which have been in use twenty-four years in the United States.

Here, let us pause and ask if the labors of the authors and of the officers of S.E.G. have been justified in the publication of our *Journal;* that is, justification to themselves, to the Society, to the annual meetings, and, last but not least, for the companies, large and small, who pay the expenses of the majority of those who attend the meetings. No doubt an emphatic affirmative answer is due. The same answer, with equal emphasis, may be given as to the A.A.P.G., S.E.P.M., and to the companies who pay the expenses of their members attending the annual meetings. I wish to emphasize the answer as it relates to the number of representatives the various companies send to annual meetings, the cost the companies incur, and the number of papers their employees present orally and by publication. The managements of some companies are more liberal than others, both as to attendance and as to papers contributed by employees. I think we may say to every company that whether it sends few or many representatives to the meetings, whether its employees have contributed one or a number of papers, each company receives many times the value for both the time and the money invested, in both tangible and intangible results. No one company, at the present time or in the past, has equalled the research and development of the combined total of all the others.

Now, however, sixteen years after our Society's organization and publication, two results are to be recognized. First, instrumentation, field technique, and interpretation have reached a rather stable and advanced stage under our present conception of seismic, gravimetric, and magnetic instruments. Second, sufficient drilling has been done as a result of geophysical and combined geophysical-geological work whereby the time is ripe for publication of geophysical case histories.

It is my desire, on behalf of our Society and its officers, to urge the full sup-

port, not only of our S.E.G. membership, but also that of A.A.P.G.–S.E.P.M. officers and their members, in the publication of *Geophysical Case Histories*. This volume will be analogous to the two volumes which the A.A.P.G. published under the title *Structure of Typical American Oil Fields*.

The executive committee of S.E.G. has authorized publication and has appointed L. L. Nettleton, very able editor of our journal *Geophysics*, as editor of what we hope and expect to be the first of several volumes.

Including the five case histories given at this Chicago meeting, and one "read by title," we now have a total of twenty-six contributions consisting of approximately 375 pages—or roughly one-half the material required for the first volume.

Eighteen oil companies maintain their own staffs to design and manufacture their own geophysical equipment. There are approximately fifteen who regularly, and many others who intermittently, use the services of more than fifty contract geophysical companies. This does not include American companies doing geophysical work in foreign countries. Surely, in the files of all these oil companies there is more than adequate material which can and should be made available for the first volume.

The contents will be of great value to management, geologists, geophysicists, and to others in the oil companies. Our universities and colleges, especially those teaching subjects related to exploration, will be able to use the volume to good advantage. We have already had requests for, and have furnished, large scale maps and other data for such classroom use.

In soliciting such case-history manuscripts for this annual meeting we have in some instances encountered resistance. One point of objection is that a given oil or gas field has not been fully developed and the information might be used adversely. In such cases, by using only a dashed line showing the approximate area of production, by using no section or survey lines, and no land ownership names, this objection can be overcome. The second objection is that everyone is very busy. The companies should encourage publication for the mutual benefit of employer and employee; in addition, writers are willing to work after office hours.

In summary:

1. The need exists for publishing more geophysical case histories. Such histories are essential to management, geologists, geophysicists, especially the younger ones, and for use by professors and students in universities and colleges.

2. A plan can be followed which insures that no information the company desires to withhold will be released, and no legal difficulties encountered. Every oil company has benefited by, and no company which contributed to the two A.A.P.G. typical oil-field volumes has suffered from such contributions. Geophysical volumes should have a similar benefit, and no adverse effects.

3. One-half of the material is available in printed form at the present time for the first volume. More than sufficient case history data are in the files of oil

companies, and can be readily assembled. A prompt contribution of at least one case history each from the thirty-three oil companies already referred to will be sufficient to complete the first volume.

4. This is, therefore, an urgent request to the members of the three societies, and through them to their companies, for prompt co-operation so that our first volume may be published soon. I believe the services our Society has rendered in the past to every oil company merit such co-operation.

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FACING FORWARD[1]

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New York, New York

Through several generations the world has become accustomed to look to science for solution of the physical problems of living. But at no time in the past, I think, have people looked so earnestly to science as they do to-day. Both the obligations and the opportunities facing the scientist are great.

Some of these fall within his traditional function of creating and supplying new materials, machines, and energy sources. But there is also the obligation, and in some ways a heavier one, for the men of science to broaden their vision and contribute to the solution of complex social problems—problems which, at least partly, are the result of the very rapidity of our progress along technical lines.

Satisfaction of material needs is a huge task for all branches of science. More of all the material things people use will be needed to rebuild what war destroyed and to provide for the greatly increased demands of peace. More of the earth's great store of natural resources must be found and brought to use in new and better ways. New branches of science, new tools, and new industrial techniques will appear.

In the field of science in which the interest of this group particularly centers, that of petroleum geology, the task ahead is especially large. Some economists have estimated that in the United States, for example, oil production will average $1\frac{1}{2}$ billion barrels per year over the next twenty years. To end the period with our present reserves undiminished, this means that the industry must find some thirty billion barrels of *new* oil—a quantity equal to the total production by the domestic industry over the eighty years of its existence.

Large areas of the continental United States remain but sparsely tested for oil. Deeper drilling in present producing areas also affords a vast field for search. But the petroleum geologist will likely have to use to the fullest all his ability for unfettered thinking, imagination and the creation of new concepts of oil occurrence and accumulation. Improved and perhaps new finding tools must come in the future. The challenge thus presented should be an incentive and an inspiration—particularly to the younger geologist who has ahead of him a vast frontier. The prospects are at least as stimulating—and in some ways far more so—than at any time in the past.

The industry's whole history is a monument to changing concepts and free play for initiative. In the early days, oil finding depended on almost pure hunch and intuition. Then came the primitive stages of early petroleum geology. The

[1] An address before the Association at Chicago, April 2.

[2] President, Standard Oil Company (New Jersey).

gradual development of this science, changing and advancing in its conception and solution of the earth's secrets, is something with which we are all familiar and in which we can take pride.

Someone has said that the search for oil begins in the head. Certainly the "atmosphere" in which the search for oil is conducted has much to do with its success.

One of the most important sources of progress in our industry has been competitive spirit and free play of initiative. These factors, I firmly believe, have been largely responsible for the fact that the United States has realized much more of its potential oil resources than has any other country. From our approximately one-eighth of the world's possible oil land we have won nearly two-thirds of all the oil so far used by mankind. We have become distinguished as a nation on motor-driven wheels. Per person we use many times more petroleum than people of any other country.

Certainly, the reason does not lie in a gift of nature. Some other nations with equal prospects for oil have not been able to develop enough to meet their own needs. And the answer is not alone one of superior technical training or skill—all of us here know that there are excellent geologists and engineers elsewhere.

The answer is not so much the kind of tools we use but *how* they are used. Wallace Pratt—a true philosopher of geology—stated this well. He has written—

> . . . Three factors combine to make Americans stand out as discoverers and developers of oil in the earth up to the present. These factors are:
> (1) A distinctive flair for effective teamwork between science and industry which arises out of the American concept of the dignity of labor.
> (2) The freedom from political and social barriers to widespread exploration for oil beneath the surface of the earth in the United States.
> (3) The adventurous, chance-taking spirit of the pioneer which pervades America and has impelled Americans to drill thousands of wells every year in search for oil.

Teamwork, freedom, initiative—these are sound arguments. And of these, I suggest, freedom—freedom of opportunity and freedom to exercise initiative—has been the keystone. For without it the others would have been of but little value.

This freedom to search for and find oil—the absence of barriers to participation by anyone in the search—has, in the last analysis, been one of the major factors of our "atmosphere" and one which has been lacking in much of the world abroad. Oil in this sense is truly a product of freedom.

With this freedom—or as a result of it—we have had the spur of healthy competition. This has meant progress and vitality. From America has come by far the greatest portion of the technological advance in the finding, producing, and refining of petroleum. Most of the industry outside the United States uses American techniques, and equipment of either American manufacture or based on American design.

So much for the past. What of the future? The industry's strides in technical achievement over the past several decades justify confidence that, given the same opportunity, there need be no fear for the future in petroleum. We can be confident that just as our geological science has been a living and growing thing, we can count upon future technological developments to continue to bring to use the hidden stores of oil.

On this point, Dr. Robert E. Wilson has, I believe, employed an apt term—" . . . technology is the multiplier of our resources." Just one of many examples is the advance in oil recovery techniques. We have learned how to increase the amount of oil recoverable from oil reservoirs from scarcely more than 20 per cent to as high as 80 per cent of oil in place.

Further, we have already assured ourselves against that day, should it ever come, when natural petroleum is no longer to be found in necessary quantities and at reasonable cost. We have, in effect, taken out our own insurance on liquid fuel supply! For the techniques of converting into liquid fuel our natural gas and our tremendous resources of solid fuels are already well advanced. We know that we can—when, as and if necessary—provide the United States with practically unlimited quantities of liquid fuel made from gas, coal and shales at costs which will not be prohibitive.

Certainly, then, the question of our ability to provide for the long future is not "can it be done?" but perhaps "shall we have the opportunity?" Can we insure that our potential will not be made impossible of realization? Here we come to a consideration of social questions. Their proper solution is far more important than even the most revolutionary advance in science—for science is but a part of society and the health of the whole will determine the health of a part.

It is hardly necessary to list some of these problems facing us to-day. Our daily papers are full of them. Differences between races and groups; divergent economic and political theories; problems of labor and management, conflicting thoughts between nations.

One which bears directly on industries such as our own is the concept that favors State ownership and operation of natural resources. Oddly, many who advocate this seem to do so in the belief that the centralized authority of the State can find and develop natural resources better than can private citizens. They seem completely to overlook actual history. For our own nation, the greatest exponent of private competitive enterprise, has been overwhelmingly more successful than all those which have practiced various degrees of Statism throughout the past 150 years.

Significantly, the basic principle of American democracy,—that no group or combination of men are wise enough to direct in detail for the whole—is so firmly a part of our thinking that it is also a cornerstone of successful industrial management. For example, in my own company, extensive and varied operations are carried on by various affiliates. And officers of each affiliate have full responsi-

bility under the coordination and policy guidance of the parent company. This not only develops individual initiative but fosters a spirit of healthy competition —implacable enemies of complacency and stagnation.

However skilled, however well intentioned, the single center can not, I firmly believe, match the potentialities of the many. A major problem facing this nation —and much of the world abroad that is not yet thoroughly regimented—is to find and keep the happy mean between the extremes of centralization and the anarchy of jungle-law competition. The ingredients of personal freedom, incentive for use of initiative, and the spur of competition must be retained for progress, while Government—the people speaking as a whole—furnishes guidance for the general welfare. Football without rules or a referee would be anarchy—with too many rules or overly officious referees it would stagnate.

This field of social problems—and what is coming to be called social science—has in the past been marked more often than not by solutions based on emotion rather than on reason. The techniques of the scientific method—the research for fact—so outstandingly successful in the physical side of our civilization have not as yet adequately been applied to our social sphere. Our human engineering has not kept pace with our physical engineering.

This neglect should be repaired. It is ironic, in a way, that we have not approached solution of our social problems with the same technique of thorough organization and open-minded search for truth that we have come to accept as routine in physical science.

The necessity for repair of the disparity was set forth recently by a prominent sociologist. In *Harper's Magazine* for December, 1945, Dr. George A. Lundberg, Professor of Sociology at the University of Wisconsin, had an article entitled, "Can Science Save Us?" In it he pointed to the gulf between our physical and social advances and made a strong plea for adaptation of the methods of modern research—the scientific method—to the study of social problems.

If by the transfusion of the scientific method into the solution of our social problems even partial progress can be made toward getting answers of fact rather than emotion, physical science will have given to civilization a gift outweighing any single technical achievement ever made.

The settling of questions of economic well-being, of politics, of international relations on the basis of the long range view and logic rather than the short term opportunistic basis commonly chosen would be a major stride forward in assuring a good future.

There is, however, a note of caution to be observed in any public pronouncement by "scientists." The basic attributes of fact-finding and objective thinking must be retained. If in discussing social problems, the scientist takes up cudgels as a partisan, he is no longer a scientist but just another pressure agent. For either an individual technologist or a group to decide on the answer to a social problem and then attempt to use the magic word "science" to force acceptance prostitutes every principle of science.

I recall reading somewhere not long ago the observation that the Industrial Revolution—applied science—beginning some two centuries ago brought mankind out of various forms of feudalism. The world has moved rapidly since—in freedom, material gains, population. But the writer foresaw danger that man had created in science a Frankenstein's monster which would but cause man to destroy himself since science had not also solved concurrent social problems. With this I do not agree—I think that we simply have not used in human affairs the tools and techniques given us by science and which are so widely applied in industry. We must start to use them.

While the physical scientist is not, of course, qualified in social science—he can and should make greater contributions to public knowledge and discussion than he has in the past. He can not, perhaps, offer solutions to social questions but he can contribute fact and knowledge where these are needed. And he can take greater part in public discussion encouraging where he can the objective approach to which he as a scientist has been trained. We may never be able to eliminate emotion from our thinking on social problems but the addition of more fact and reason would certainly help in finding the right answers.

In summary, our industry has in the past done an outstanding job in supplying the petroleum needs of our nation and, in substantial measure, of the world. The requirements for the future will be large. But our prospects at home and the fertile fields abroad make it certain that the public need have no concern about ample supply for the years ahead. Improving technology is our assurance.

The only real cause for concern lies in the possibility that restrictive measures of one sort or another may hamper our effort. These restrictions may be nationalistic in character, may be hangovers of war-born controls, or may have other forms. But whatever their origin they will not be conducive to the free unfettered thinking and play of initiative that has been the lifeblood of our industry.

This brings the field of social science into the immediate interests of the geologist, a physical scientist. For the solution reached in this and other social problems will affect his ability to go forward and develop the potentials which lie ahead.

The geologist must, I believe, look outward in the future beyond his immediate tasks, take greater interest and participation in human affairs and, in effect, be no less than the full rounded citizen that he should be. The scientist of to-morrow must not only create things—he must help to find solutions to problems of their use. And he must do his part to assure that the society in which he works will not unwittingly impose barriers to his further progress.

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SCIENCE LEGISLATION AND GEOLOGY[1]

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The year was 1879. The extravagant expenditures of the London School Board were being deplored by a witness appearing before a Committee of the House of Commons. Part of his testimony ran as follows.

> Geography, sir, is ruinous in its effects on the lower classes. Reading, writing and arithmetic are comparatively safe, but geography invariably leads to revolution.

If, in 1879, geography invariably led to revolution, where, in 1946, will nuclear physics lead us? In a significant current brochure, the atomic physicists warn that it will inevitably lead us to "One World or None." Moreover, one of their more distinguished members, the Nobel Laureate, Harold C. Urey, succinctly reveals the general apprehension of the group in the very title of one of his recent articles, which is, "I'm a Frightened Man." The well founded fears of the physicists have been communicated to the general public here and abroad.

Dean Wallace Donham of the Harvard Graduate School of Business Administration, writing prophetically in 1944, said,

> Times and men and circumstances change about your changing character, with a speed of which no earthly hurricane affords an image. What was the best yesterday, is it still the best in this changed theatre of a tomorrow? Will your own Past truly guide you in your own violent and unexpected Future?

These are burning questions which entire nations, as well as scientific organizations, and individual citizens are now seeking frantically to answer, for the future of 1945 proved to be even more violent and unexpected than Dean Donham had anticipated.

Science, by far the swiftest runner in the modern intellectual sweepstakes, has set a blistering pace for the entire past half-century. But its finishing sprint in the final pre-atomic race has been even more dazzling. Thus, although Science obviously remade our world in the past five decades, it could conceivably destroy it in the next five months.

The ever accelerating rate of scientific progress can be easily demonstrated. For instance, although I like to think of myself as a relatively young man, the civilization into which I was born as recently as the turn of the century had more in common with the non-scientific world of 1496 than it was to have with the ultra-scientific world of 1946. And, although few have been aware of the fact, we have already been living in a still more advanced scientific period—the nuclear era—for well over three years. Since December 2, 1942, when the first nuclear chain reaction was established in the experimental pile under the Stagg

[1] Read before the Association at Chicago, April 2, 1946.

[2] President, Beloit College.

Field grandstand right here in Chicago, scientific advances of transcending significance to all humanity have been swiftly taking place.

The first *public* display of our new found scientific knowledge was at Hiroshima on August the sixth, 1945, less than eight months ago. The results were so devastating *physically* that the Japanese nation was forced into swift surrender. The consequences were also so devastating *morally* that already some Americans in private and a few in public, are urging that atomic bombs be used to destroy all Russia. For the belligerent as well as the benign now know that ours is a time when the minute may be employed to master the mammoth.

The almost incalculable might of the minute can be brought home, appropriately enough, through a geological comparison which I would not employ were there many volcanologists in the audience. As it is, I refer to Krakatoa with considerable diffidence, for all of us were at one time familiar with the story of its eruption. But for the benefit of those who have forgotten the details, Krakatoa was once a volcanic island located in the Straits of Sunda between the islands of Java and Sumatra. Late in August, 1883, Krakatoa erupted in a series of violent paroxysms. It is estimated that prior to the cataclysm the island had an area of eighteen square miles and rose to a height of 1400 feet above the sea. After the explosions, the main island had vanished and there was left behind a few rocky islets, *and* a submarine cavity at least a thousand feet in depth. It is now impossible to calculate the exact quantity of rock ejected, but it has been commonly estimated as being not less than five cubic miles, or equivalent to the amount of material which would be obtained by lowering the entire 210 square-mile surface area of the city of Chicago by more than 125 feet.

During the day-time hours of the eruption, it continued dark as night at Batavia, one hundred miles away. Dust and ash were thrown into the air to a height of more than seventeen miles. The finer particles reached the higher layers of the atmosphere and were spread over much of the face of the earth. Sunrise and sunset effects of weird beauty resulted, and continued for many months and the actual temperature of the earth was materially reduced. The sound of the volcanic explosion was heard in the Philippine Islands about 1,500 miles to the north, and at Rodriguez nearly 3,000 miles to the west. Great tidal waves also were generated and may have reached as far as to the English Channel some 11,000 miles away. The oceanic disturbances entirely destroyed several hundred coastal towns with an appalling loss of human life.

Certainly the most conservative person will be forced to agree that when we describe this phenomenon as a cataclysm, we are erring on the side of understatement.

Last August I was discussing this great volcanic eruption in a setting very different from this one. The scene was a beautiful azure northern lake, the site the after-deck of a small trolling vessel. My three companions included Dr. Warren Johnson, the chairman of the department of chemistry of the University of Chicago—a man who directed much of the chemical work on the atomic bomb

—and Dr. Arthur H. Compton, the Nobel Prize winner in physics—one of the leading scientists responsible for the entire atomic bomb program. Ostensibly we were fishing for lake trout. Actually, because the explosion at Hiroshima had just occurred and the scientists were having their first real vacation from Oak Ridge, we were concerned chiefly with the new instrument of warfare, and the possible future effects of the nuclear discoveries on the very foundations of civilization.

Among other questions, I asked Dr. Compton if he were familiar enough with the eruption of Krakatoa to make a satisfactory layman's sort of comparison between it and the possible effect of a single atomic bomb. He replied that as a matter of fact the eruption had not long before been brought to his attention, and that he had therefore attempted a rough comparison on the basis of the admittedly inadequate data available. The conclusion he had arrived at was a startling one. Although it is clear that no atomic bomb exists in such a form, the equivalent of a bomb one meter in diameter would, upon detonation, result in an explosion of Krakatoan violence. That is, fissionable material of such a bulk might well be able to blow more than 125 feet off the surface of an area as large as the entire city of Chicago. I am sure that Dr. Compton should not be held strictly accountable for this rough—and rugged—comparison, but it does give us graphic evidence as to why nations and plain citizens, as well as geologists, must now be interested in science legislation.

Speaking before the Houston Geological Society in December, 1943, I said,

> . . . Politicians *will* be interested in Science when at last it is apparent to all that it cuts a big enough swath in the field of national design to have unmistakable political implications and bureaucratic possibilities. . . .

It is obvious that it has those implications and those possibilities now, and in full measure. Science has always been significant in the field of national design but *complete* realization, in high administrative circles, of the width of the swath it cuts only dates back to August 2, 1939, when Albert Einstein wrote President Roosevelt a memorandum which began as follows.

> Some recent work by E. Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the administration.

It was not until June 15, 1940, however, that the President appointed a committee for the correlation of the scientific efforts of the nation and placed its leadership in the capable hands of Dr. Vannevar Bush, president of the Carnegie Institution of Washington. More than four years later, on November 17, 1944, after it had become apparent that the nuclear energy program was to be crowned with success, the President wrote Dr. Bush as follows.

> The Office of Scientific Research and Development, of which you are the Director, represents a unique experiment of team-work and cooperation in coordinating scientific

research and in applying existing scientific knowledge to the solution of the technical problems paramount in war. Its work has been conducted in the utmost secrecy and carried on without public recognition of any kind; but its tangible results can be found in the communiques coming in from the battlefronts all over the world. Some day the full story of its achievements can be told.

There is, however, no reason why the lessons to be found in this experiment cannot be profitably employed in times of peace. The information, the techniques, and the research experience developed by the Office of Scientific Research and Development and by the thousands of scientists in the universities and in private industry, should be used in the days of peace ahead for the improvement of the national health, the creation of new enterprises bringing new jobs, and the betterment of the national standard of living.

It is with that objective in mind that I would like to have your recommendations on the following four major points:

First: What can be done, consistent with military security, and with the prior approval of the military authorities, to make known to the world as soon as possible the contributions which have been made during our war effort to scientific knowledge?

The diffusion of such knowledge should help us stimulate new enterprises, provide jobs for our returning servicemen and other workers, and make possible great strides for the improvement of the national well-being.

Second: With particular reference to the war of science against disease, what can be done now to organize a program for continuing in the future the work which has been done in medicine and related sciences?

The fact that the annual deaths in this country from one or two diseases alone are far in excess of the total number of lives lost by us in battle during this war should make us conscious of the duty we owe future generations.

Third: What can the Government do now and in the future to aid research activities by public and private organizations? The proper roles of public and of private research, and their interrelation, should be carefully considered.

Fourth: Can an effective program be proposed for discovering and developing scientific talent in American youth so that the continuing future of scientific research in this country may be assured on a level comparable to what has been done during the war?

New frontiers of the mind are before us, and if they are pioneered with the same vision, boldness, and drive with which we have waged this war we can create a fuller and more fruitful employment and a fuller and more fruitful life.

I hope that, after such consultation as you may deem advisable with your associates and others, you can let me have your considered judgment on these matters as soon as convenient—reporting on each when you are ready, rather than waiting for completion of your studies in all.

Four advisory committees were set up by Dr. Bush for study of, and report on, the questions raised by the President. The chairman of the third committee was Dr. Isaiah Bowman, president of Johns Hopkins University and distinguished geologist and geographer. Dr. Bowman's committee met on November 14, 1945, and, in a notable report to the President, declared in favor of the Magnuson Bill, S.1285, which had been introduced in the Senate on July 19 in an attempt to translate into legislation the recommendations of Dr. Bush's epoch-making report entitled "Science: The Endless Frontier." The committee, however, was opposed to including the social sciences under the same administration with the so-called basic sciences, though not adverse to the social scientists receiving separate support.

Much earlier, in the fall of 1942, Senator Harley M. Kilgore of West Virginia had introduced in the Senate a Science Mobilization Bill. Despite the fact that, in one way or another, the Government had been directly sponsoring scientific research since the War of 1912, neither the Congress nor scientists were receptive to the Bill. The fact is, rightly or wrongly, both it and its author were to a very real extent discredited. Subsequently, however, Senator Kilgore has, in the minds of scientists generally, rapidly grown in stature. His address, "Science and the Government," delivered before various scientific representatives in Washington on December 5, 1945, was a statesmanlike declaration. Appearing in the December 21, 1945, issue of *Science*, it has had wide reading and reasonably general favorable acceptance.

During 1945, as a result of the issuance of the Bush report and the later recognition of the success of the nuclear researches, several bills involving science legislation were brought before the Senate. It is not the purpose of this paper to summarize them. Suffice it to say that largely through the efforts of various scientists, and several scientific associations, S.1720 was introduced on December 21st. This new Kilgore Bill, with Senators Fulbright, Johnson, Pepper, and Saltonstall as co-sponsors, embodied changes and improvements sufficiently significant that it provided a new and more satisfactory basis for discussion.

In January, Senator Thomas of Utah brought Senators Kilgore and Saltonstall in contact with representatives of the so-called Committee Supporting the Bush Report. Modifications of S.1720 were proposed and finally accepted. These were incorporated in S.1850 which was introduced on February 21, 1946, as the Kilgore-Magnuson Bill with Senators Ferguson, Fulbright, Johnson, Pepper, Saltonstall, and Thomas as co-sponsors. Some of the provisions of the bill are briefly summarized as follows.

1. A National Science Foundation is established under an administrator appointed by the President, with the consent of the Senate and after consultation with the National Science Board.

2. A National Science Board is created. It is to be made up of nine persons appointed by the President by and with the advice and consent of the Senate and the Chairman of the several Divisional Scientific Committees.

3. The following Divisions are to be established within the Foundation: (a) Mathematical and Physical Sciences; (b) Biological Sciences; (c) Social Sciences; (d) Health and Medical Sciences; (e) National Defense; (f) Engineering and Technology; (g) Scientific Personnel and Education; (h) Publications and Information; and (i) such additional divisions not to exceed three in number as the Administrator, after advice from the Board, may establish. Each Divisional Committee, except National Defense (40—half civilian, half appointed by Secretaries of War and Navy, with an Executive Committee of 9—a Chairman, and 4 civilians and 4 military appointees) shall consist of 5 to 15 members appointed by the Administrator with the advice and approval of the Board. The Board and each Divisional Committee elects its own Chairman annually. No member of the Board or of the Committee who has served a full three-year term can succeed himself until the expiration of one year after his term has expired.

4. "The Board shall continuously survey the activities and management of the Foundation, and shall periodically evaluate the achievements of the Foundation in accomplish-

ing the objectives of this Act. Each divisional scientific committee shall survey continuously the scientific field which it encompasses, shall undertake to determine the specific scientific needs of such field, and shall evaluate proposed programs and projects. Until general recommendations have been received from the Division of Social Sciences concerning the needs for research in the field of the social sciences, the support of research in the social sciences shall be limited to projects recommended by such Division as are related to the impact of scientific discovery on the general welfare."

5. The Bill authorizes the awarding of scholarships and fellowships " . . . in any field of science, including but not limited to the mathematical, physical, biological, medical, and social sciences at nonprofit institutions of higher education, or other institutions, selected by the recipient of such aid, for such periods as the Administrator may determine, in the United States or in foreign countries."

6. The Bill establishes a national register of scientific personnel.

7. The Bill provides for the use and dissemination of research findings.

It is hoped that the recent introduction of the Willis Bill (S.1777) and the one proposed by Congresswoman Luce (H.R.5332) will not unreasonably complicate the issue. Bill S.1777 proposes a research foundation somewhat similar to the Academy of Sciences, with the 40 members of the foundation to be nominated by the Academy. The Luce Bill would create a Department of Science and Health with a secretary of Cabinet rank.

Who are in favor of a National Science Foundation? On the basis of returns from a questionnaire, the A.A.A.S. believes that more than 90 out of every one hundred American scientists are. Approximately 100 prominent scientists participated in the Government hearings held in October, but only one witness in the group was opposed to a Government-sponsored foundation. The Association of American Colleges, however, is not so sure. At its meeting of January 9–11, 1946, it passed, with only minor changes, the following pertinent resolution.

RESOLUTION II: In view of the current proposals before Congress and the country respecting Federal subsidies to research in the natural sciences, the Association of American Colleges urges that attention be given to the following considerations:

(1) In the present state of affairs it is imperative that research relating to human welfare, health, and security be prosecuted with greater imagination and with greater vigor than ever before in our history. While research in the natural sciences is unquestionably important for our national security and material progress, research in the social sciences and the humanities is equally essential if we are not to increase the gap between scientific and technological discoveries and our ability to adjust the social, economic, and political patterns of our society to those discoveries.

(2) Research in the past has been made possible through private benefactions to colleges and universities and through corporate expenditures in industrial laboratories. We believe that this method has many advantages over Federal subvention and that some modification of the tax structure, particularly with respect to the provisions for charitable contributions, would be no more costly and far more desirable than increased tax revenue which would then be diverted to research purposes.

(3) Nevertheless, if it should be decided that the Federal Government should embark on a program of direct subsidy to research, we recommend that an independent governing board be established. While we consider the provisions of Senate bill 1720, introduced on December 21, 1945, and sponsored by Senators Kilgore, Johnson, Pepper, Fulbright, and Saltonstall, superior in many respects to its predecessor, we believe that it would be even

more desirable to create a board the members of which should be selected as proposed in S. 1720, for their competence and range of interest, but who shall serve without compensation and who shall preferably be self-perpetuating. The board should have the power to use the money at its disposal for whatever research programs shall seem necessary and desirable. It shall render annual reports to the Congress, which in turn will exercise control through its power to make periodic appropriations of funds to the board.

What do geologists think about it? Well, we must consider the problem from at least three possibly similar, but probably different, points of view. As plain citizens we must ask ourselves what the pending science legislation may mean to us as members of the world community. As scientists we need to anticipate what the enaction of any measure may imply for all members of the international scientific fraternity. As geologists we must understand what it may signify for all those who study, teach, or practice the geoscientific disciplines.

Are there straws to show which way the geological wind is blowing? There is at least a partial indication to be found in the resolution sent by the Geological Society of Washington on March 13, 1946, to the President and the Congress. Although it concerned the McMahon Bill, S.1717, rather than the Science Foundation directly, its wording is revealing.

"We, the 400 members of the Geological Society of Washington, D.C., unanimously endorse the McMahon Bill S.1717 in its original form." The Society which never before has concerned itself with legislative matters stated that no bill will provide a satisfactory domestic policy on atomic energy that does not provide for: (1) Full control over atomic energy development in this country by the Federal Government; (2) Complete civilian control through a Federal agency—the role of the military to be restricted to liaison in the field of weapons; (3) A policy of free publication and dissemination of scientific information, restricted only by the provisions of the Espionage Act. "We further believe that a bill lacking any of these features will stifle scientific progress and will, consequently, irreparably harm our civilization and greatly weaken the national defense."

I realize that this Association can not lightly abandon its long-standing tenets and become engaged directly in issues which, however scientific, are also partially political. But it would be gratifying if there could be devised, within the limitations imposed by our Constitution, as well as by tax hazards, a method for our going on record as being in favor not only of S.1717, but also of the Kilgore-Magnuson Bill, S.1850. I leave it to the sagacity of our astute executive committee to devise ways and means.

Should these Bills, or similar Bills, become law, how will geology and geologists be affected? Not adversely, I should judge; but if we are placed at any greater disadvantage than we now sometimes seem to enjoy, it will only be because we continue to take a perverse delight in resisting unification in our scientific organizations.

I have spent many hours in reading the voluminous House and Senate Hearings on the various aspects of pending scientific legislation, including the proposals for the control of atomic energy. Of course, the physicists, quite properly,

had a field day. Without really meaning to do so, through their great achievements they contrive to make the work of other scientists appear almost inconsequential. It may, therefore, be necessary for someone to point out to the possibly faint-hearted geologist that the physicist puts on his scientific pants one leg at a time just as we do, and sometimes gets a little tangled in them at that.

Ideally all sciences should be cooperative, not competitive; and the physicists are generally as lost in a geological gabfest as the geologists are in a nuclear discussion. I should like to illustrate the point by quoting briefly from the Hearings.

Senator Byrd: "Where are the known deposits of uranium now?"
Dr. Irving Langmuir: "I don't know much about it."
Senator Byrd: "Then you are not certain they have been discovered in Russia."
Dr. Langmuir: "Not personally, no; but I have heard . . . that there are deposits in Russia."
Senator Byrd: "I was told on good authority that no deposits have been discovered in Russia . . . "
Dr. Langmuir: "Yes, but when you think what a large fraction of the surface of the earth is covered by Russia, and how little we know about it, and how much the Russians know about it, it is reasonable to assume that there are such deposits."

Drs. K. T. and A. H. Compton were nearly, if not quite, as lost when questions of geological import were put to them. Dr. Harlow Shapley, however, discussed geological items accurately, mentioned Carboniferous fossil plants, and, in order to make a point, even brought a rock to the Hearings. Perhaps more important still, Dr. Vannevar Bush has a fair notion of at least one potential role geologists could play in the new scientific world. Witness this transcript of testimony.

Dr. Bush: " . . . The nations of the world might . . . make available completely through the United Nations Organization full information in regard to the sources of ore of the principal fissionable materials. . . ."
Senator Tydings: "All the raw materials?"
Dr. Bush: "All the raw materials. . . . We know just about where they are in the world in general, and it would not take a great inspection system to determine whether such facts as were supplied by every nation were correct or not. In fact, it would take very little beyond the visit of a few geologists . . . to know what the facts are. . . ."

Dr. Clarke Williams of the College of the City of New York also referred to the need for "specialists in the fields of geology and mining . . . "

Possibly as a result of this growing appreciation of the value of geologists and things geological there has been set up, by the Committee on Atomic Energy of the Carnegie Endowment for International Peace, a Committee on Inspection of Raw Materials which has the sponsorship of the G.S.A. and the A.I.M.M.E. Under the chairmanship of Dr. Paul F. Kerr, the committee issued, in February, 1946, an important Conference Report on International Inspection of Radioactive Mineral Products.

This is a gratifying start in the right direction. The importance of the project can not be overstated because some authorities now believe that atomic energy

could one day, perhaps rather soon, release many of the peoples of the world for fine arts, service trades, and education. And because, mishandled, it might well release all life, this latter threat could possibly force man into being more humane. Radioactive elements can and ultimately will be used not only in the reduction of labor and the increase of production, but in medical, biological, and agricultural experiments of far reaching consequence. It has even been suggested that eventually we may be able to obtain energy from almost any kind of matter, and produce, at will, any kind of substance or material desired. If this were to prove to be the case, nuclear energy could bring near equality to all peoples of all nations, for under such a circumstance the so-called unequal distribution of the traditional natural resources would be of minor significance.

If any or all of such semi-wishful thinking turns out to be translatable into realization in the near future, what geological materials are likely to be involved? Anyone may get the consensus of the present guesses of best informed physicists by reading a part of Bill S.1717.

"A Bill for the development and control of the atomic energy" which contained—as of January 22, 1946—the following definition under Section 5b: "The term 'source materials' shall include any ore containing uranium, thorium, or beryllium, and such other materials peculiarly essential to the production of fissionable materials as may be determined by the Commission with the approval of the President."

This leads me to cite another brief excerpt from the Senate Hearings on Atomic Energy which might conceivably have bearing on the very future of the A.A.P.G.

Senator Hart: "All of our talking and thinking thus far has been based on uranium or some other very heavy material. . . . Do you visualize science progressing to the point that much more plentiful and more widely distributed materials may become fissionable . . . ?"

Dr. J. R. Oppenheimer, the former head of the Los Alamos Laboratory: "No; with the exception of the very heavy elements, it will take some very new idea and some new discovery to extract energy from them. My frank opinion is that for all *but the very light* and the heavy elements the project will not be successful; that is, I do not think that iron will ever be a source of energy. I say that with the full confidence that I may read in tomorrow morning's paper that somebody has found a way. . . ."

But the very light elements which presently have proved most tractable are the very stuff of petroleum, and they are readily available. The inherent dangers to the profession of petroleum geologist are surely far from immediate, but it would be unscientific to maintain that they are completely non-existent. The New York *Times* in a considerably less speculative comment on Atomic Power recently put it this way: "Coal and oil may yet cease to be bones of economic contention, and uranium deposits may be coveted instead."

In conclusion, it should be pointed out that at a time wherein we are striving desperately for a workable United Nations Organization the scholarly disciplines themselves are still more nationalistic than many nations. Professor John S. Perkins, a social scientist of Boston University, writes, "Science did it. The

physical scientists won the war. It is now up to the *social scientists* to win the peace."

The chemists, a little annoyed at the way the physicists have taken the best scientific ball away from them are not waiting for a National Science Foundation to help them. They have set about to improve their own game.

The American Chemical Society will award fellowships aggregating $210,000 in 1946 and 1947 to aid in the training of chemists and chemical engineers, it has been announced by Bradley Dewey, president of the Society. Pre-doctoral students whose work was interrupted by the war will receive $100,000. Grants of $110,000 will be made to holders of the doctor's degree who desire to devote one or two years to research and teaching. Funds for the program have been allotted from a $500,000 educational fund established by the Society.

The pre-doctoral fellowships will carry an annual stipend of $1,200 for single candidates and $1,800 for married candidates, plus a maximum of $500 a year for tuition and laboratory charges. Post-doctoral fellowships will carry a stipend of $2,500 a year, with the understanding that the institutions at which the recipients study will provide an additional sum, presumably at least $1,000 a year, for teaching. Awards will be for one year, and will be renewable for a second year upon proof of satisfactory performance.

Geologists, too, need to improve their science at the source. What work we have done, although important, has usually been carried on too far downstream. But perhaps the most interesting of all evidences of parallel scientific nationalism is provided by the biologists. In November 30, 1945, issue of *Science* there appears this discussion:

> American biologists who have been aware of the inefficient way in which the potential contributing power of biologists was utilized in our recent war effort have had forcefully called to their attention one of the serious consequences of lack of general organization. Even more impressive indications of the need of organization, since they concern not the past but the future, are such matters as (1) the immediate need of more intimate international relations of scientific societies to parallel international cooperation along other lines, and (2) the *prospects of the availability for distribution shortly of large federal funds for the furtherance of scientific training and research.* Biologists now constitute the only major scientific group lacking a strong unifying organization. Their present organization consists of dozens of small societies, each concerned with a highly restricted area of biology and acting independently of most of the others. They lack entirely any body that can speak and act authoritatively for biologists as a whole.

If you will substitute for the terms "biologists" and "biology," the words "geologists" and "geology" you will have our own story. But then many geologists have spoken about it before. My own views on the subject have been presented at length, in depth, and *ad nauseum.* But even if we badly needed a central geological organization in the past, it is going to be still more desperately required in the future. It will become a sheer necessity when the National Science Foundation eventuates for many obvious reasons, as well as for the all too obvious mundane one given by the biologists, namely, "the availability shortly of large

federal funds for the furtherance of scientific training and research." When they become available, which present geological organization will be able to represent adequately all American geologists, or the totality of American geological sciences? Will it be the G.S.A.? The A.A.P.G.? I think not.

Eugene Holman, in delivering a recent commencement address at the University of Oklahoma, began as follows.

> Some thirty years ago when I opened my first geology text book I learned a lesson which I have always remembered. I learned that the earth, which I had always though of as so substantial and unchanging, is actually changing continually.

Nevertheless, as geologists we resist changes in our own organizational world. In effect, we become similar to the great physician who has difficulty both in diagnosing and in treating the ills of his own family.

Sir Josiah Stamp, the famed British economist, not so many years ago propounded the irritating dictum, "Scientists should always be on *tap*, never on *top*." Knowing the glacial slowness of some British as well as American geologists, I have sometimes toyed with the notion that Sir Josiah's pronouncement is possibly related to the fact that his brother is the distinguished English geologist, Dudley Stamp. But to-day scientists are not only on tap—many are at or near the top. Moreover, there are highly appreciated geologists among them.

Even more encouraging is the growing spirit of amity among geologists who, better than any other group of scientists, know that in the organic history of the earth Conflict is a Methuselah—Cooperation is merely a newborn babe. The Conference on Training in Geology held at the G.S.A. meeting last December under the direction of Dr. Chester Longwell is a fine example of new and better geological cooperation. Another is the friendly and objective scientific spirit which pervaded the last Washington meeting of representatives of the various geological societies interested in the proposed American Geological Institute, and the subsequent deliberations of committees appointed at that meeting. These committees have prepared reports which will soon be made available to the geological fraternity, and I venture respectfully to request their sympathetic consideration.

Legislation of international import confronts the world in the agenda of the United Nations Organization. Legislative measures, in the form of the National Science Foundation proposals, which are of national significance for American citizens and scientists, are before the Congress. Unification procedures not only of geological utility but also of general scientific value are awaiting action by this great professional association. I dare to hope that in the very near future all such proposals will be acted on, and favorably.

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GEOLOGISTS' PLACE IN SERVICE[1]

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ABSTRACT

Geologists were used in this war, both in uniform and as civilians, more than during World War I; however, the potential value of geologists has never been fully realized.

Personal experience in the European Theater demonstrated the possible uses of geology in the occupational or reparative phase of war, involving reconstruction and economic rehabilitation.

Geologists are of greatest value for war during times of peace by assembling and coordinating complete data concerning all portions of the earth. These same data can and should be used for the general betterment of man, but should war come they will be found of inestimable value.

INTRODUCTION

Even though firing ceased several months ago, we are still, and will be for many years, trying to emerge from a war that demanded all the abilities and energies of the nation—a war of science in which the scientists of nations were competing, both in the fields of research and economics and in the actual theaters of operation. It might be correctly called a total war, a war of materials or of resources.

The science of geology contributed its part, both in tactical and strategic planning, consciously or otherwise, and in the location and production of resources required by the industries and machines of war. However, we know that the potential value of geology and geologists has never been fully utilized, either in times of war or in peace. This group, the American Association of Petroleum Geologists, more than any other, pressed for the further utilization of geologists, but often their pleadings fell upon deaf ears. The great value of the fine work of the military geology unit of the United States Geological Survey is now known by some; it is an example of what can be done. However, the war was well advanced before the military authorities saw the need and possible value of such experts. Perhaps now is the time to take such necessary action that will assure the use of the science to fuller possibilities in the future.

In contrast to the slogan during the first world war as a "war to end all wars," and while we all hope that there will never be another total war and must all do our utmost to prevent a recurrence, it might not be out of order to give consideration to future wars (as some believe that the best preventive of war is preparedness), to point out that the period between wars is the most important and yet the most neglected. I now believe that the greatest possible value of the geologist for war lies in his activity between wars, by the compilation and coordination of full geological and economic data on all portions of the earth's crust.

In the past the United States, and all non-aggressive nations for that matter, have tended to consider future wars in terms of previous wars.

[1] Read before the Association at Chicago, April 2, 1946.

[2] State geologist of West Virginia. Professor and head of department of geology, West Virginia University.

In order to formulate any recommendations for the future of military geology, it is necessary to consolidate knowledge gained in the past and keep it before us, together with progress of research and development.

To enumerate before this group the possible uses of geology as applied to war, a subject which has already been presented many times,[3] would be "carrying coals to Newcastle."

We geologists have too long lamented the fact that we are unappreciated and our field of specialty is not sufficiently recognized. If it be true that our field is not generally appreciated, it will not be corrected by our complaints. We must quit feeling sorry for ourselves and the neglected position we feel our science occupies when others of the natural sciences are mentioned and geology is omitted. It is time to get off the defensive and take the offensive by demonstrating by concrete examples.

I. PART PLAYED BY GEOLOGY IN WAR PRIOR TO WORLD WAR II

Despite the fact that great military leaders have always made subconscious use of geology, taking into account the physical factors within the theaters of operation and having an intimate knowledge and superior appreciation of terrain, there was never any attempt made before World War I at definite organization.

The Germans were perhaps the first to realize the scope of military geology and, as they already had a superior coordination of geology and engineering, it was no great step to impress upon military authority the importance of utilizing geologists in staff positions.

The United States had the groundwork laid for them by being able to observe the uses the Germans and British were making of geology.

By the end of the war all the major armies had geologic sections— the Americans had an authorized staff of eighteen geologists, six at General Headquarters, five with each of the two armies, and two in line of communications.

The United States has never supported a strong peace-time military organization, although "history has demonstrated that we have thereby neither avoided war nor deterred others from going to war,"[4] and the geologic staff disappeared from the military set-up.

If the number of papers written on military geology can be used as a barometer, there was a decided lapse of interest in the application of geology to war in the period between the world wars. Exceptions were the development of aerial photography and photogrammetry, and some indication of closer alliance between geology and engineering, which must preface any hope of incorporating geology firmly and permanently in the military structure—perhaps the best proving ground for war geology.

[3] Paul H. Price and Herbert P. Woodward, "Geology and War," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 12 (December, 1942).

[4] H. H. Arnold, "Air Power for Peace," *National Geographic*, Vol. 89, No. 2 (February, 1946), p. 137.

German papers covering all phases of military geology indicated, as early as 1933, a revival of the geologic corps and development to a known geologic section of nine men to each army.

Again in 1942, the utilization of geology by the American forces followed the example set by another nation. The Corps of Engineers, on learning that some 600 German geologists were engaged in North Africa and Italy, was reputedly dissatisfied with the geologic information it was getting, and a barrage of inquiries directed at the United States Geological Survey resulted in the formation of the military geology unit.

It is reported that the variety of questions received indicated that few army officers were sufficiently familiar with the scope of geology to know what kind of information the Survey could supply. It follows that, if geology is to be used as an effective tool, an appreciation of its uses must be included in a much wider program of education than in the past.

Judging by the rapid increase in scope of work of the military geology unit and extension to teams being sent into combat areas, and considering that this was but one of several agencies contributing geologic information and assistance, civilian organizations were much more widely utilized in World War II than previously.

Although the organized geologic staff authorized during the first world war was never reinstated, and in World War II there were very few geologists receiving commissions as such, there were some geologists scattered throughout the military structure who were making good use of their knowledge and training.

II. GEOLOGY AND GEOLOGISTS IN WORLD WAR II IN THE EUROPEAN THEATER

Considering the number of men with geologic training (estimated at some 2,000) scattered all through the army, assigned to various branches of the service, I believe it must be said that they were seldom effectively used as such. In discussing the subject with other geologists, it seems that my own experience was better and that I was more fortunate than most in being able to apply past training and knowledge to the jobs at hand.

World War II added a vast new field of work—the problems of civil restoration behind our fast-moving armies and following the policy of destruction for hindrance and delay of the retreating enemy—which did not exist in the static nature of previous wars. It was in these problems of rebuilding and restoration that it was possible to apply geology and geologic training.

During an invasion the problem of maintaining civil order is second only to the defeat of the enemy. No field commander can afford to have a population rioting and looting along his lines of communication and along the extended lines of supply which were the vital arteries of the army in the last war; thus food, utilities, and fuels must be made available as rapidly as possible. Water supply is of utmost importance in every town, both from the standpoint of civil control

and protection of our own troops from communicable diseases. Following these immediate local problems come the larger nation-wide adjustments, involving fuel, natural resources and their allied industries, and transportation—the re-establishment of a nation's economy.

My work was along these lines, first in France, later in Germany. It was a huge problem and could be handled better by special units, specifically trained for the purpose and self-contained, than by strictly combat units. The original plan, which was well conceived and for which a training program was carried out, was to do this with a special division of the army, Military Government. Just as quickly as areas were taken, Military Government Detachments, composed of numerous specialists in the fields of public safety, sanitation, public utilities, and resources, moved in.

Should Military Government have failed, as some claim, an opinion in which I do not entirely concur, it was not the fault of Military Government, but of other Branches of the Army's failure to cooperate.

After a one-month period of indoctrination at Fort Custer, I attended the Civil Affairs (Military Government) Training School at Stanford University, the latter part of which was spent, together with Captain L. E. Kemnitzer, in the preparation of a report on the mineral resources of Germany. This report was reproduced and made available to other military government schools, where it was used as a reference or handbook.

Upon arrival in England, I was attached to a British unit as trade and industry, and mining specialist, which included resources. The British looked with favor on improving one's knowledge of the areas into which we were expected to go, and agreed with my proposal to visit the Geological Survey of Great Britain in London for data on mineral resources, particularly of France, Belgium, and Germany. British civilian agencies were used extensively by the army for the preparation of reports and maps.

Our British detachment arrived in France in the latter part of June close on the heels of the invasion. Although most of the coastal towns were largely destroyed and some completely abandoned, the former inhabitants would soon straggle back. The problem of water supply was immediately presented.

The town of Bayeux, near the coast of Normandy, was supplied by springs, which were sufficient for normal needs; but the influx of thousands of troops drained the reserve supply and the spring flow was inadequate. The French complained that the springs would be irreparably damaged. My conclusion was that they were not being damaged, but recommended that near-by streams be treated and used for the troops, leaving the springs for the town supply.

Another water supply problem developed in the small town of La Gravier. Their public source of water had been a large spring which was destroyed by bombing. The advance party reported the situation grave, and, although the town was then abandoned, the former residents would soon be filtering in. Here I was able to locate some six old wells in town, and new ones could easily be drilled on

a near-by flood plain where ground water was within 3 feet of the surface.

The city of Argentan, which was 80 to 90 per cent destroyed, got its water supply from deep wells into the Cretaceous chalk. The reservoirs were shot full of holes, the pump motors had been removed by the Germans, and the lines into the city broken in many places. A new source must be found. Finally, a good well, formerly used by a creamery which also boasted a sizable concrete tank, was discovered in the center of town. Here again, however, the Germans had removed the pump and motor. A search revealed the only remaining available pump in the possession of the local fire department. Fortunately it worked and, after sterilization of the tank, a supply of safe chlorinated water was made available.

Following the bitter fighting at Falaise Gap, back of Caen, a problem for certain members of the detachment arose concerning sanitation, with regard to clearing the area of hundreds of carcasses of cattle and horses strewn over the battlefields. Their previous experience had shown that lime would at least relieve the situation, and a geologist was needed to locate such material. An investigation soon disclosed an extensive lime quarry in the area at which the required burned lime could be secured.

As part of the over-all plan to restore French economy by developing local resources, it was of vital importance to establish indigenous resources to highest possible productivity as soon as possible. The problem of coal was one of the most urgent—all of the coal on the continent was in German hands, and the army had to supply its needs from Great Britain and the United States. The invasion must proceed a long way before important indigenous resources would be available; the areas where invasion took place had no coal except for one small deposit.

This deposit proved to be an old coal development; its shafts had been abandoned for many years. I was fortunate in locating an old Bureau of Mines report which gave the depth of the coal and other data indicating probable reserves, and was able, after inspection, to make an estimate of the time required to put the mines into operation again. The investigation disclosed that there would be no advantage to the allied cause because of time involved.

It was not until we reached northern France that any indigenous coal of importance was available. Here the vast Pas de Calais du Nord field, which supplied 75 per cent of the coal of France, was regained, bringing with it the problems of mine reconditioning, operation, and distribution, and the allied economies of coke, gas, synthetic fuels, chemicals, and power. The entire field lay in the sector for which our detachment was responsible.

The mines of the area, under enemy domination for so long, had been pushed to their productive limit without replacement of equipment, and the requirements for resumption of normal production were many.

In this same area were the large chemical and synthetic fuel plants, among them the one important Fischer-Tropsch plant in France. The need for fuels, oils,

lubricants, and gasoline was acute (gasoline was so scarce that French civilians would go to any limit to get it), and it was of vital importance to re-establish these sources as soon as possible.

It was in this great industrial Pas de Calais du Nord region that my past experience served me well. The industrial economy of northern France was, to a smaller degree, analagous to that of West Virginia, with the exception of natural petroleum and natural gas. That economy was based on coal, with the closely allied industries of coke, manufactured gas, chemicals, and power; and required an understanding of their needs, their inter-dependence, their problems of production and distribution. My former experiences enabled me to fit easily into the position of liaison officer between the army and the local officials of industry; to inspect and investigate the coal, fuel, and chemical industries; and to estimate productive capacities.

It was here at Lille that I found concrete evidence of German thoroughness. A two-volume report prepared by the Germans had been left there and came into my hands. One volume was a set of ten maps showing the location of all coal mines; gas plants and gas lines; water plants and water lines; power plants and power lines; chemical plants, including liquid oxygen and nitrogen plants; a map showing all other natural resources from clays to sand, and gravel pits and aggregate quarries; also, agricultural crops. The second volume contained full descriptive data—ownership, productive capacities, statistics, *etc.* Not having been told of my find, my colleagues could not understand how I had so quickly become an authority on the region of northern France.

Pierre Pruvost, Dean of the Faculty of Sciences at the University of Lille, was a well known geologist in Europe, especially for his knowledge of coal. He had both taught and travelled in America and was partial to Americans. Dr. Pruvost had been badly treated by the Germans, and was all the more eager to offer all possible assistance. He had made studies and reports on the coal fields of Europe, and from him I secured valuable information and geologic reports on the Pas de Calais du Nord fields of France and the Saar fields of Germany. Through him I was able to learn much concerning areas I was to enter later as well as at Lille.

An interesting illustration of the value of knowing where to locate sources of information was the incident of intelligence work on the V-2 bomb. At that time the source and composition of these bombs was unknown, and every possibility was being traced, including the suspicion that liquid oxygen was being used. From this same German report I had the location of each plant in the region and was able to get from the industry's records the amounts procured by the Germans, where it was sent, and the method of transportation.

As Germany proper was now to be invaded, the system of combined civil operations was discontinued, and I was transferred to Solid Fuels Section of G-4 SHAEF, and later made chief of the unit of the coal section which was to take over the Saar coal field.

The lapse of time before the Saar was actually overrun permitted a detailed

study of reports and maps in order to become familiar with the exact location of the mines, sources of power, water, productive capacities, and the geology of the coal basin. By assembling all available information, a very complete picture of the Saar could be constructed.

During this period of study, I was impressed by the possibility of concealment of enemy troops and equipment in mine shafts and tunnels, and wondered whether or not our troops had this information. Upon inquiry at Headquatrers, I learned that no such information had been available, and that they were very anxious to secure all possible data of this kind. We were able to give information in such detail that a special G-2 report, showing mine shafts, tunnels, *etc.*, was furnished the troops.

In taking over and operating the mines, geology in itself was not a requisite, but of definite value in the problems of production. Incidentally, the first big problem here was to prevent the destruction of mines and equipment by Ukranian labor that had been brought in to mine coal. There were some 17,000 of these laborers on the loose, bent on destruction and revenge. Geologic training and especially experience with Geological Surveys made for a much clearer understanding of the inter-relation of industries. This is evidenced by the fact that Louis C. McCabe of the Illinois Survey was chief of the German sub-section, and George C. Branner, State geologist of Arkansas, was located at Supreme Headquarters with the Solid Fuels Section from its inception.

After the Saar was turned over to the French, we were assigned to the production Control Division of G-4, Coal and Non-metallics Section, for the American Sector. Here a knowledge of geology and mineral resources was very important; our section investigated and prepared reports on those resources, coal and non-metallics, for the American Zone of Occupation. The work often required inspection of the operations, so that we were able to visit coal mines (brown coal), salt operations (both rock salt and brines), potash, pyrite, and shale oil distillations.

III. FUTURE

While I am reluctant to think it, I believe that man will always wage war. Perhaps there may have been some justification for earlier wars and there may be for future wars. However, no nation ever started what it considered an aggressive war. Now that man can wage war so efficiently and has become so proficient in killing and general destruction, dreadful consequences lie ahead. Since wars are invariably precipitated by unbalanced economic conditions, the geologist's greatest opportunity and greatest obligation is to work for better world conditions by helping to make available more of nature's resources to more people.

If, however, wars are inevitable, then let us not be caught off guard, as has been our custom, but be prepared to meet any challenge that may be put to us. In order to wage efficiently a defensive war (but on enemy territory), complete information on that country is necessary beforehand; this includes good maps showing topography, geology and economic resources, soils, all transportation facilities and other man-made developments. Of special importance for future

wars is a knowledge of opportunities for underground concealment in existing mines and caverns, both in our own country and in enemy territories. Much of this is the field of the geologist.

All these data should be had long before actual conflict begins. The time to secure these data is not after war is imminent or the conflict has begun, but now. From this material special reports covering the needs of each arm of the service could be prepared.

In the light of my own experience, I would say that geology and the geologist are needed in the prosecution of war from the planning phase, during conflict, and during the reparation phase, with special emphasis on planning and occupation or reparation, as compared to the combat phase.

The number of geologists, the time and place, and branch of service to which they are to be attached, must be governed by conditions existing at the time. For example, before the war our knowledge of Europe was far greater than our knowledge of the Pacific—maps and full reports were available in numerous libraries—the planning staff and field commanders had or could have had most all the information that geologists could secure were they actually on the ground. In the Pacific conditions were quite different; there the geologist was needed in numerous capacities because conditions to be encountered were not known beforehand.

To what extent our peace-time army's table of organization calls for well trained geologists I do not know, but I would strongly recommend that our G-2 (Intelligence) include a branch whose sole responsibility would be to secure as full data as possible on those portions of the globe for which we do not now have such information, these data to include maps, resources, climate, *etc.*

General Arnold has so correctly said, "Of vital importance is a system of intelligence of a much more far-reaching character than we have had before. Our past conception of intelligence needs was insufficient to cover the requirements of modern war."[5]

Geology should have an important place in this intelligence, both in times of war and in periods of peace, to collect, evaluate, and disseminate information through proper channels.

The Corps of Engineers needs geologists at all times. The Navy needs geological data on their numerous island bases and petroleum reserve fields. The Air Corps requires geological data on airfield sites and in aerial photograph interpretation. The other branches of the service require various types of geological information from time to time, depending upon local conditions. An army of occupation should be made up of specialists in all fields; a knowledge of resources is basic, hence geologists are required.

The best time to collect and evaluate these important data is during times of peace. Such information, properly utilized, may aid in the prevention of war, but should war come we will be prepared.

[5] H. H. Arnold, *op. cit.*, p. 170.

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HISTORY OF RESERVES AND PRODUCTION OF NATURAL GAS AND NATURAL GAS LIQUIDS IN TEXAS[1]

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ABSTRACT

The natural gas and natural gas liquids reserves have been divided into three categories because of current producing and regulatory practices. These categories are (1) non-associated gas (free), (2) associated gas (gas cap), and (3) dissolved gas. The total reserves of these three categories in Texas as of January 1, 1946, were about 75 trillion cubic feet, divided (1) 69 per cent, (2) 22 per cent, and (3) 9 per cent. The number and volume of natural gas discoveries have increased materially in recent years and the year-end reserve has increased steadily.

Natural gas liquids are defined as the liquids being recovered from the three categories of gas by current plant or field practices. The total natural gas liquids reserves in Texas were about 1.5 billion barrels with about 52 per cent in the non-associated gas, 21 per cent in the associated gas, and 27 per cent in the dissolved gas.

The gauged gas production in Texas in 1945 was about 2.9 trillion cubic feet or a daily average of 79 billion cubic feet. The natural gas liquids produced during 1945 in Texas were about 61.5 million barrels or a daily average of 168,000 barrels.

INTRODUCTION

For the past several years, the subject of natural gas and natural gas liquids has become increasingly important. A variety of influences and factors have contributed: (1) cycling operations have been found profitable; (2) as wells are drilled deeper, the industry has been finding more commercial gas reserves; (3) oil fields with sizable reserves are becoming more difficult to find; (4) recognition of the necessity of reducing gas wastage has become a major issue with the State regulatory bodies; (5) the federal Power Commission has instigated hearings in an attempt to regulate sales price based on producing costs and to control the end use of gas; (6) the growing use of natural gas as a raw material for synthetics, plastics, and fuels has increased the demand; (7) the opposition of the coal industry and unions to the competition of gas in the fuel markets; (8) the stand of some of the members of State regulatory bodies to the exportation of gas from their states; (9) the increased demand for carbon black in the making of synthetic rubber products, *etc.;* (10) the oil companies' cooperation with the regulatory bodies in the conservation of gas has made it one of the most important studies of the day. There probably are several other reasons. The possibility of commercial sulphur from sour gases similar to that obtained from the plant at the McKamie field in Arkansas could be mentioned. This plant is now producing about 60 tons a day of sulphur from sour gas, although the plant was built in order to sweeten the gas for commercial uses and not to produce sulphur. The main point is that the industry is now interested in gas and its liquefiable products and probably will become more interested in the immediate future.

Gas is usually found incidentally or accidentally—incidentally when it is

[1] Read before the Association at Chicago, April 2, 1946.

[2] Humble Oil and Refining Company.

found dissolved in oil, and accidentally when it is found instead of oil. It is seldom that a wildcat well is drilled solely for gas. For this reason, in many cases when gas is discovered, the well is either shut-in until a market is found or is used for fuel to drill other wells in search for oil.

Natural gas was first used as a fuel in western China in about 200 A.D. to evaporate brines. It was first used as an illuminant in New York state in 1821. The first commercial pipe line was laid in 1883, from Murrysville, Pennsylvania, to Pittsburgh. The first gas compressed was in 1890 in the Murrysville field, when the gas was transported by high-pressure pipe lines. The long-distance transmission lines from the Southwest started in 1925 with the advent of oxy-acetylene welding and improved seamless carbon-steel pipe.

The natural gas reserves and contained liquids in Texas have been divided into three categories: (1) non-associated gas or free gas not associated with oil in the reservoir; (2) associated gas which is gas overlying an oil reservoir as a gas cap; and (3) dissolved gas or the gas in solution in the oil in the reservoir which is released when the oil is produced. The non-associated gas and the associated gas together make up what is generally called free gas, and the part of the associated gas produced with oil and the dissolved gas is called casinghead gas. These three categories were established because of the current conservation practices and the Railroad Commission regulations. All gas figures to be shown will be on a pressure base of 14.65 pounds per square inch absolute.

The non-associated gas represents about 69 per cent of the total gas reserves. This is the gas produced from gas wells in Texas, and in general the only restriction is that the production must be marketed and the allowable can not exceed 25 per cent of the open-flow potential. Allowables have been set in only a few fields of this type to date. This non-associated gas is the gas generally produced through cycling plants or into gas pipe lines for fuel.

The associated gas, representing about 22 per cent of the total gas reserve, is restricted to cycling operations and those quantities produced with oil as casinghead gas. On October 20, 1944, the Texas Railroad Commission changed its Rule 6 to read that the amount of gas which could be produced from a gas well in a gas cap is limited to a volumetric displacement of oil and gas equivalent to a 2000:1 ratio on the highest oil allowable. Under this ruling, the oil allowables of high ratio wells are penalized, and the only way a gas cap can be utilized is to cycle the gas and strip the heavier hydrocarbons. For this reason, it is necessary to separate the *free gas* reserves into the part available for market and the part which can be cycled only.

The dissolved gas designation is the same as has been used for years and represents the gas liberated from solution in the oil as it is produced. This is the remaining 9 per cent of the gas and is generally produced through natural gasoline plants when the volume and yields are sufficient to warrant the construction of a plant. In fields where there are no plants, the dissolved gas is either used for fuel, compressed and put into gas pipe lines, used for repressuring or gas lift or

flared. It should be kept in mind that there is no material physical difference between these three gases. The distinctions are solely on the basis of their position in the reservoir as related to oil and whether in a single-phase or two-phase reservoir.

The history of the gas discoveries in Texas has been one of ever increasing volume. The tables to follow will show these discoveries and the relationship between the three categories. In these tables the total reserves of each field are credited to the year in which the field was discovered.

NATURAL GAS DISCOVERIES BY YEARS

Table I shows the accumulative discoveries by five-year intervals of the three categories of gas. Dissolved gas was first discovered in Texas in 1865 in the Nacogdoches field. Free gas and, in this case, associated gas was first discovered in the Petrolia field in North Texas in 1904. The first non-associated gas was

TABLE I

STATE OF TEXAS NATURAL GAS CUMULATIVE DISCOVERIES, PRODUCTION, AND YEAR-END RESERVES AT FIVE-YEAR INTERVALS, 1900–1945, INCLUSIVE

	MMCF						
	Cumulative Discoveries				*Production*		*Est. Year-End Reserve*
	Non-Assoc.	*Associated*	*Dissolved*	*Total*	*Yearly*	*Cumulative*	
Prior to 1901	—	—	5,462	5,462	650	650	4,812
1905	—	37,500	152,642	190,142	11,000	32,263	157,789
1910	200	37,500	158,201	195,901	8,000	69,163	126,738
1915	19,834	89,475	603,833	713,142	30,324	169,054	544,088
1920	30,962,510	432,675	1,055,125	32,450,310	80,019	416,080	32,034,230
1925	32,080,432	1,056,634	1,884,434	35,021,500	418,964	1,796,157	33,225,343
1930	32,974,393	2,612,177	5,850,947	41,437,517	967,880	5,611,280	35,826,237
1935	40,088,266	12,622,674	8,339,179	61,050,119	1,218,085	10,754,444	50,295,675
1940	60,890,446	18,525,529	11,114,939	90,530,914	1,523,650	17,470,863	73,060,051
1945	68,045,936	21,626,944	12,904,662	102,577,542	2,607,177	27,481,714	75,095,828

discovered in Southwest Texas in the Gas Ridge field in 1912. In the early part of this century, gas discoveries in Texas were plugged and the rig was moved to another location or else the operator "let-her-blow" until the head was off and oil was produced. The dissolved gas discoveries increased, of course, with the discovery of oil and reached a peak in 1930 when the East Texas field came in. In that year a total of almost two trillion cubic feet of dissolved gas was discovered. The associated gas discoveries had several peaks but reached a maximum in 1934 and 1935 when a total of about 8 trillion cubic feet of associated gas was discovered. The most recent peak of purely non-associated gas discoveries was in 1939 when the Hugoton (Texas portion), Paradis, LaGloria, and Agua Dulce fields were discovered for a total of about 9 trillion cubic feet. However, the largest volume of non-associated gas discovered was in 1920 when the Panhandle field was brought in. The gas in this field is classified as non-associated gas. The five-year period, 1935 to 1940, showed gas discoveries in Texas of almost 30 trillion cubic feet or an average of 6 trillion cubic feet a year. This is equivalent to the current production of the entire United States.

There has been a total of 2,231 gas reservoirs discovered in Texas since beginning. In this count of reservoirs, there were 756 non-associated gas reservoirs, 508 associated gas reservoirs, and 967 dissolved gas reservoirs. The dissolved gas reservoirs were counted as fields instead of separate reservoirs. Southwest Texas has first place in non-associated and associated gas reservoirs with 426 and 262, respectively. The Texas Gulf Coast is second in both categories with 244 and 168 reservoirs, respectively. The greatest number of dissolved gas reservoirs is in North Texas where 298 fields have been found as compared to 282 in Southwest Texas and 188 in the Gulf Coast. The number of non-associated gas reservoirs found has materially increased in recent years. Twenty years ago in 1926 there were only 9 non-associated gas reservoirs, 10 associated gas reservoirs, and 46 dissolved gas reservoirs or oil fields found. In 1945 there were 148 non-associated, 51 associated, and 102 dissolved gas reservoirs found. This is a complete reversal in the number of discoveries by categories in this 20-year period. However, the total number of reservoirs discovered in Texas by years has increased from a low of 32 in 1931 to a high of 307 in 1944 or almost ten times in 15 years. 1945 was very close to 1944 with a total of 301 reservoirs of all classes.

The average volume of gas discovered per non-associated gas discovery is 90 billion cubic feet. The associated gas discoveries averaged 42 billion cubic feet, and the dissolved gas discoveries averaged 34 billion cubic feet. The State average for all discoveries of gas was 46 billion cubic feet per discovery.

The production of gas was relatively small until about 1925 when production reached a billion cubic feet a day as compared with the current rate of about 7 billion cubic feet a day for the state. This is about 44 per cent of the estimated 16 billion cubic feet a day produced in the United States. This seven fold increase in gas production in Texas has been in a period of 20 years. Oil production has increased only five times in the same period. The estimated cumulative gas production since beginning is 27.5 trillion cubic feet or about 27 per cent of the total gas discovered. In comparison, the oil discoveries have been depleted 43 per cent. This estimate of production includes all gas produced, gauged, and vented from oil and gas wells.

Gas reserves in Texas have been constantly increasing until they now exceed 75 trillion cubic feet. In the last 5 years over 2 trillion cubic feet have been added to these reserves notwithstanding a production of almost 10 trillion cubic feet in the same period.

NATURAL GAS DISCOVERIES BY DISTRICTS

Table II shows that of the 102.6 trillion cubic feet of gas discovered in Texas since beginning, 68 trillion or 66.34 per cent was non-associated gas, 21.6 trillion or 21 per cent was associated gas, and 12.9 trillion or 12.58 per cent was dissolved gas. Of this amount about 40 per cent of the total gas found was in North Texas. This is due primarily to the huge Panhandle gas field and the Texas part of the Hugoton field. The second most important gas area in Texas in the Gulf

Coastal region with total discoveries of 24 trillion cubic feet. Southwest Texas is third with 19 trillion cubic feet, with East Texas fourth, and West Texas a poor fifth. Of the non-associated gas. North Texas, Gulf Coast, and Southwest Texas maintain the same order as the total, with Southwest Texas a close third to the Gulf Coast. The West Texas area has very little associated gas since the larger reserves are found as gas caps or associated gas. The Gulf Coast area takes the lead for associated gas with 9.9 trillion cubic feet, with Southwest Texas and West Texas second and third. The West Texas area with its large oil reserves

TABLE II

STATE OF TEXAS CUMULATIVE NATURAL GAS DISCOVERIES BY DISTRICTS SINCE BEGINNING

	MMCF							
	Non-Associated		*Associated*		*Dissolved*		*Total*	
	Total Discovered	*Per Acre*	*Total Discovered*	*Per Acre*	*Total Discovered*	*Per Acre*	*State*	*Per Acre*
GULF COAST	11,874,654	65.0	9,935,418	54.3	2,390,386	12.4	24,200,458	60.3
% District	49.07		41.05		9.88		100.00	
% State	17.45		45.94		18.52		23.59	
EAST TEXAS	7,424,780	21.9	1,791,442	24.1	2,432,084	10.3	11,648,306	20.0
% District	63.74		15.38		20.88		100.00	
% State	10.91		8.28		18.85		11.36	
SOUTHWEST	11,841,109	36.8	5,590,502	32.8	1,677,934	5.6	19,109,545	29.9
% District	61.96		29.26		8.78		100.00	
% State	17.40		25.85		13.00		18.63	
WEST TEXAS	158,075	4.2	3,040,076	18.1	3,747,476	5.7	6,945,627	9.8
% District	2.28		43.77		53.95		100.00	
% State	.24		14.06		29.04		6.77	
NORTH TEXAS	36,747,318	16.3	1,269,506	6.4	2,656,782	5.2	40,673,606	14.6
% District	90.34		3.13		6.53		100.00	
% State	54.00		5.87		20.59		39.65	
TEXAS	68,045,936	21.7	21,626,944	27.3	12,904,662	6.8	102,577,542	20.0
% State	66.34		21.08		12.58		100.00	

and gas-drive fields has discovered the largest volume of dissolved gas. The gas-drive fields produce not only the gas in solution with the produced oil but also the gas in solution with the oil which is left in the reservoir. The 3.7 trillion cubic feet of dissolved gas in that district represents 29 per cent of the state total of dissolved gas. North Texas is second in dissolved gas discoveries, and East Texas is third. This relationship is not true of oil reserves. The East Texas area is first in ultimate oil reserves, but due to the low solution ratio (320) in the East Texas field, the volume of gas found was not as large in proportion. This lack of volume in the East Texas field is more than compensated by the yield of liquids, which is about 4 gallons per 1000 cubic feet.

This table also shows the volume of gas found per acre for each district. The Gulf Coast, with an average of 60.3 million cubic feet per acre, has twice the volume of the next best district, Southwest Texas. The East Texas district will yield an average of only 20 million cubic feet per acre, and West Texas an average of about 10 million cubic feet. The State average is 20 million cubic feet per acre. The associated gas discovered averages 27.3 million cubic feet per acre as against the non-associated average of 21.7 million cubic feet, and the dissolved gas average of 6.8 million cubic feet. This would indicate rather large gaps caps. The greatest average discovery per acre by categories is an average of 65 million cubic feet per acre of non-associated gas in the Gulf Coast district. On a B.t.u. equivalent of 6,000 cubic feet per barrel, this is equal to about 11,000 barrels per acre.

NATURAL GAS RESERVES BY DISTRICTS

Table III shows the natural gas reserves for the state of Texas by districts as of January 1, 1946. The total reserve is 75 trillion cubic feet or equivalent to 12.5 billion barrels of oil on a B.t.u. basis, of which 24.6 trillion cubic feet or

TABLE III

STATE OF TEXAS GAS RESERVE AND PROVED GAS ACRES AS OF JANUARY 1, 1946, BY DISTRICTS

	Non-Assoc. Gas		*Associated Gas*		*Dissolved Gas*		*Total*		*Avg. Res. Per Surf. Acre MMCF*
	Prod. Acres	*MMCF Reserve*	*Prod. Acres*	*MMCF Reserve*	*Prod. Acres*	*MMCF Reserve*	*Surf. Acres*	*MMCF Reserve*	
G. COAST	182,602	11,320,209	182,681	8,807,120	193,174	1,435,925	401,051	21,563,254	53.7
% Dist.		52.50		40.84		6.66		100.00	
% State	5.82	21.90	23.05	53.33	10.19	20.81	7.84	28.71	
EAST	338,685	6,683,124	74,055	1,111,444	235,630	1,336,080	581,721	9,130,648	15.7
% Dist.		73.20		12.17		14.63		100.00	
% State	10.80	12.93	9.35	6.73	12.43	19.37	11.36	12.16	
SO. WEST	321,877	10,000,807	170,550	3,933,953	300,215	1,035,731	639,147	14,970,491	23.4
% Dist.		66.80		26.28		6.92		100.00	
% State	10.26	19.35	21.52	23.82	15.83	15.01	12.49	19.94	
WEST	37,690	132,715	167,690	2,262,207	656,250	2,459,556	710,709	4,854,478	6.8
% Dist.		2.73		46.60		50.67		100.00	
% State	1.20	.26	21.16	13.70	34.60	35.64	13.88	6.46	
NORTH	2,255,500	23,543,267	197,500	400,500	510,980	633,190	2,786,230	24,576,957	8.8
% Dist.		95.79		1.63		2.58		100.0	
% State	71.92	45.56	24.92	2.42	26.95	9.17	54.43	32.73	
TEXAS	3,136,354	51,680,122	792,476	16,515,224	1,896,249	6,900,482	5,118,858	75,095,828	14.7
% State		68.82		21.99		9.19		100.00	
1945 Pdn.		1,803,465		692,200		425,264		2,920,929	
% State		61.74		23.70		14.65		100.00	
Ratio Pdn. to Reserve		28.66		23.86		16.23		25.71	

33 per cent is in North Texas, 21.6 trillion cubic feet or 29 per cent in the Gulf Coast district, and 15 trillion cubic feet or 20 per cent in Southwest Texas. On a B.t.u. basis, therefore, Texas' gas reserve represents about the same number of barrels as the oil reserve.

North Texas, including the Panhandle, accounts for about 46 per cent of the state's non-associated gas reserves. The Gulf Coast is second with 22 per cent and Southwest Texas is third with 19 per cent. This totals 87 per cent, with the balance in the other two districts. The associated gas reserves are located principally in two districts, the Gulf Coast and Southwest Texas, with 53 and 24 per cent, respectively. The dissolved gas reserves are principally in West Texas, Gulf Coast, and East Texas districts, with 36, 21, and 19 per cent, respectively.

Although the North Texas-Panhandle area contains 33 per cent of the total gas reserve of the state, it has 54 per cent of the proved surface area, indicating a comparatively low average yield per acre. The 2.8 million acres have an average reserve of only about 8.8 million cubic feet as compared to the average of 14.7 million for the State and 53.7 million for the Gulf Coast.

The production of natural gas for the year 1945 in the state of Texas was 2.9 trillion cubic feet, which is a ratio of 26:1 on the state's reserve as compared to the oil ratio of about 16:1 reflected by the dissolved gas production ratio. This gas production ratio is on a gross basis without considering the cycled and repressured gas. On a net basis, the ratio is about 30:1.

The non-associated gas production is about 62 per cent of the total, and the associated gas is 24 per cent, with the dissolved gas 14 per cent. If the B.t.u. equivalent of 6,000 cubic feet to a barrel of oil is used, the production of equivalent barrels would be about 1,600,000 barrels a day.

NATURAL GAS LIQUIDS RESERVES BY DISTRICTS

Table IV shows the natural gas liquids of pentane plus contained in the gas reserve figures shown on Table III. In fields where cycling or natural gasoline plants are available and capable of extracting propane and butane, these liquids are included in the estimates. Almost all of the liquids reserves have been estimated on the basis of actual yields rather than calculated yields.

The reserve of natural gas liquids in Texas as of the first of January, 1946, was 1.5 billion barrels, which is equivalent to about 12.5 per cent of the oil reserves of the state. These reserves were divided 52 per cent in non-associated gas, 21 per cent in associated gas, and 27 per cent in dissolved gas. The important difference in percentage between the gas reserve and natural gas liquids reserve is in the dissolved gas which has only 9 per cent of the gas reserve but 29 percent of the liquids reserve. This is due to the higher yield from the dissolved gas. The dissolved gas has an average yield of 59 barrels per million cubic feet as compared to 15 barrels for the non-associated gas and 19 barrels for the associated gas. The State average is 20 barrels. The Gulf Coast has the greatest percentage of the natural gas liquids reserve with 30 per cent. North Texas is second with 23 per cent and East Texas is a close third with 22 per cent.

The reserve of natural gas liquids per acre is largest in the Texas Gulf Coast. This district has a reserve of 1,142 barrels per acre, whereas East Texas and Southwest Texas have 580 barrels and 326 barrels per acre, respectively. The

TABLE IV

STATE OF TEXAS NATURAL GAS LIQUIDS RESERVES AS OF JANUARY 1, 1946, BY DISTRICTS

	1000's Barrels								Avg. Yield Per MMCF Bbls.
	Non-Associated Reserve		Associated Reserve		Dissolved Reserve		Total Reserve		
	Total	Per Acre	Total	Per Acre	Total	Per Acre	Total	Per Acre	
GULF COAST	238,647	1.307	183,632	1.005	35,622	.184	457,901	1.142	21.2
% District	52.12		40.10		7.78		100.00		
% State	30.58		58.39		8.73		30.47		
EAST TEXAS	107,460	.317	24,363	.329	205,583	.872	337,406	.580	37.0
% District	31.85		7.22		60.93		100.00		
% State	13.77		7.75		50.40		22.45		
SOUTHWEST	139,562	.434	43,772	.257	24,861	.083	208,195	.326	13.9
% District	67.03		21.03		11.94		100.00		
% State	17.88		13.92		6.10		13.86		
WEST TEXAS	433	.011	50,778	.303	107,250	1.63	158,461	.223	32.6
% District	.27		32.05		67.68		100.00		
% State	.06		16.15		26.30		10.54		
NORTH TEXAS	294,292	.130	11,925	.060	34,545	.068	340,762	.122	13.9
% District	86.36		3.50		10.14		100.00		
% State	37.71		3.79		8.47		22.68		
TEXAS	780,394	.249	314,470	.397	407,861	.215	1,502,725	.294	20.0
% State	51.93		20.93		27.14		100.00		
1945 Production	33,326		10,282		17,952		61,560		
% State	54.14		16.70		29.16		100.00		
Ratio Pdn. to Reserve	23.42		30.42		22.72		24.41		
% Total Oil Production	4.43		1.37		2.39		8.19		

average for the state is 294 barrels per acre. This does not include the possible conversion of the lighter gases into liquids.

NATURAL GAS LIQUIDS PRODUCTION

The 1945 production of natural gas liquids in Texas was 61.5 million barrels or about 168,000 barrels per day. The ratio of liquids production to reserve is 24:1 and represents about 8 per cent of the total oil production.

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TRENDS AND DEVELOPMENTS IN PETROLEUM PRODUCTION ENGINEERING[1]

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ABSTRACT

This paper summarizes the important trends and developments in production engineering, particularly for the period since 1941. This period has had an important influence upon the trend of engineering development because of the fact that the high wartime rates of oil production afforded an opportunity for quantitative observation and evaluation of petroleum reservoir characteristics under controlled conditions.

It is the writer's opinion that the most important development in petroleum engineering within recent years has been the inauguration of the transition from the qualitative to the quantitative stage. This transition is not complete but is in fact just sufficiently developed to be reaching the period of vigorous further growth and advancement. The groundwork for this quantitative stage has been built and the future should bring a degree of quantitative engineering control far surpassing expectations of a few years ago. This trend is illustrated with examples of technically controlled development and operation of selected oil reservoirs and the basic and applied research which forms the basis for the trend is briefly reviewed.

The suggestion is made that to keep pace with progress in the industry the technical man, engineer or geologist, must recognize the necessity of abandoning qualitative thinking and must adapt himself to the more difficult task of quantitative study. Those unable to accommodate themselves to this progressive change will lose ground in the same manner as has occurred in many a manufacturing industry when the processes have advanced from art to science.

INTRODUCTION

The purpose of this paper is to present for the returning veteran a brief review of developments since 1941 in petroleum production engineering. It is directed primarily to those items and trends which are thought to be significant and important to the geologists dealing with production in the technical sense. No attempt has been made to review the entire field of petroleum engineering. For example, no mention is made of advances in drilling techniques or equipment improvements. It is recognized that such items form an important part of petroleum engineering and that they have a direct bearing on the cost of finding and producing oil. However, such phases do not overlap the technical field of geology. This paper is concerned primarily with those matters in which the engineer and the geologist have a common professional interest, the mutual problems of development and exploitation of oil pools.

EFFECT OF WAR ON PRODUCTION TECHNOLOGY

The war severely interrupted a vigorous activity in production technology; much promising research in progress in 1941 was discontinued and many technical field studies were curtailed because of diversion of geologists and engineers from their normal pursuits to the armed services or to other functions. Thus, while certain branches of science were greatly stimulated and phenomenally advanced during the war, including electronics and nuclear physics, no correspond-

[1] Read before the Association at Chicago, April 4, 1946.

[2] Humble Oil and Refining Company.

ing activity took place in the technology of oil production. It is probable that during the more than four years that have elapsed since the beginning of the war the technical progress in oil production has not exceeded one to two years' normal advance. Hence, those who have been away from the profession for three to five years have only a reasonable amount of new factual knowledge to assimilate. On the other hand, a significant development has begun to assume recognizable shape during this interim and it is important that the returning veteran recognize it, appreciate it, and accommodate himself to it.

It is possible that the returnee has here an advantage over those who have stayed too close to their jobs, burdened with added wartime responsibilities, and too confined to details to appraise critically the technological changes taking place in the industry. While his war duties may have been such as to leave no time for thought of the technical details of geology, nevertheless his absence may have given the veteran an opportunity to consider his profession objectively with the detachment of an outsider.

DEVELOPMENT OF QUANTITATIVE PRODUCTION TECHNOLOGY

The significant development now under way is the transition from the qualitative to the quantitative stage of oil production technology. The development did not start during the war, or even immediately preceding it; it was hindered technically rather than promoted by the war-created shortage of scientific personnel. On the other hand, possibly of much greater and far-reaching importance than this temporary interruption was the sharp focus brought to bear by the war urgency on the need for quantitative accuracy instead of intelligent guesses in the operation of petroleum reservoirs. Not only was production technology forced into the limelight, but it was accorded an acceptance which hardly could have been foreseen a few years before. Industry committees, cooperating with state and federal regulatory agencies, gathered large volumes of technical data, calculated oil and gas reserves, and estimated maximum efficient rates of production for all important flush fields. The realization that maximum efficient production rates could be calculated with sufficient accuracy and assurance so that they could be used as the guide to production during a period of unprecedented oil demand, and the almost universal acceptance of the maximum efficient rate as a yardstick, brought to production technology a stature which it probably would not have reached in many years of peacetime operations. Along with the tremendously increased rates of production in certain areas, opportunity was afforded for quantitative observation of the effects of increased production on previously restricted fields. Thus, the effect of the war was not entirely negative in the technical sense. It made obsolete the qualitative approach, rushed the poorly prepared quantitative approach through a very short adolescence, and created an acceptance of production technology which places on the engineer and the geologist a responsibility which he must accept if the technical opportunities thus opened are to be exploited.

It is immaterial at this stage to trace the exact beginning of the quantitative application of scientific principles to oil production. A few isolated individuals made pertinent scientifically acceptable observations from time to time as long as 40 or 50 years ago. Their work was often overlooked or not appreciated and was more frequently forgotten than exploited. The environment was not yet ready for these energy bursts to set off a technical chain reaction. A gradual acceleration of the frequency of such studies continued until the 1930's, during which time the number of technologists doing significant research and engaged in technical field work became sufficiently large to produce a continuously significant and growing scientific literature. Much of this work was qualitative and semi-quantitative. General principles were established, but their exact application to specific producing reservoirs was yet to come. This qualitative work was yielding ground rapidly to the quantitative toward the 1940's, when progress was interrupted in late 1941. Technology in oil production is now coming of age. The qualitative picture of the mechanics of oil reservoir operation is essentially complete. A fair start has been made on a quantitative understanding and evaluation. In the immediate future a tremendous acceleration should come in the quantitative study of every phase of oil reservoir development and exploitation.

EXAMPLES OF QUANTITATIVE TECHNOLOGY

In order to simplify discussion of the many overlapping and complex problems encountered in oil production, the various phases which must be quantitatively studied have been arbitrarily classified in the following sequence.

1. The fluid properties of the oil, gas, and water which occupy petroleum reservoirs
2. The characteristics of producing formations
3. The chemical and physical behavior of the fluids in their porous habitat
4. The behavior of wells, including their testing, completion, production, and repair
5. The characteristics and behavior of petroleum reservoirs
6. The interrelation between reservoirs and their surroundings.

It is essential in any particular operation that accurate information be available on each of the subjects enumerated. Their mutual interrelation and interdependence must be determined for each specific reservoir if development and exploitation are to be undertaken on a sound basis. It is readily apparent that both engineering and geology are involved and that no sharp distinction can be drawn between the two.

By way of specific illustration of the importance of individual items in an over-all analysis of a particular problem and the manner in which quantative studies have been employed, several typical examples are reviewed briefly.

FLUID PROPERTIES

It has been known for many years that when oil is produced a reduction of volume occurs as a result of the escape of gas from solution. Devices for measuring the shrinkage and the amount of gas dissolved in the oil and methods of estimating the shrinkage have been reported in the literature from time to

time. In many companies the determination of shrinkage factors and their use in estimating reserves has become routine. Seldom has the shrinkage factor been considered, however, as a controlling item either in reserve calculations or in the particular exploitation method employed to recover the oil from a pool. Recently, phenomenally high shrinkage factors have been encountered in several pools. In the North Lindsay pool in McClain County, Oklahoma, producing from the Ordovician at 11,000 feet, the shrinkage was found to be so great that only 0.44 barrel of stock-tank oil is recovered when a barrel of reservoir oil is produced.[3] Several other deep fields have recently been found in which the solution gas-oil ratio approximates 2000 cubic feet per barrel and the shrinkage 50 per cent. When it is borne in mind that reservoir pressure decline can cause shrinkage of comparable magnitude in the oil remaining in the reservoir, it is clearly evident that this factor alone has an exceedingly important bearing on the results which might be obtained by reservoir pressure maintenance. In reservoirs of this type, the shrinkage factor is far more of an element in the ultimate recovery than a mere correction factor to be applied to reserve calculations.

Quantitative measurement and interpretation of the properties of hydrocarbon mixtures have other applications even more elementary. Several deep reservoirs produce light hydrocarbon liquids indistinguishable from crude oil at gas-liquid ratios ranging from 2000 to 8000 cubic feet per barrel. Without quantitative information on the phase relations of such mixtures, needless expenditures are sometimes made in deepening or squeeze cementing to exclude excess gas when the only material present in the producing formation is a homogeneous gas or liquid of unusual composition.

FORMATION CHARACTERISTICS

Quantitative measurements of formation characteristics, including the determination of porosity and permeability of cores, are routine, and well completions are usually made with confidence when complete core information is available. Ordinary core analyses, however, do not always tell a quantitative story. Comparison of well productivities with the permeabilities of the exposed intervals has in many cases yielded concordant results. In other cases, however, notably in California, actual well productivities have been far less than would be expected from ordinary permeability determinations on dried cores.[4] While it has long been suspected that hydration of the producing formations, either by connate water or during drilling, is responsible for the discrepancy, the quantitative effects of such hydration were not demonstrated until core permeabilities were determined with water instead of with air as the test fluid.[5] In some areas where

[3] K. B. Barnes, "Oklahoma at Important Threshold with New Deep Pools," *Oil and Gas Jour.*, Vol. 44, No. 31 (December 8, 1945), pp. 76–80.

[4] N. Johnson and J. E. Sherborne, "Permeability as Related to Productivity Index," *Amer. Petrol. Inst. Drilling and Production Practice* (1943), pp. 66–81.

[5] N. Johnson and C. M. Beeson, "Water Permeability of Reservoir Sands," in "Petroleum Development and Technology," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 160 (1945).

commercial wells have been possible only with shooting, drilling of the producing formations with non-aqueous muds has yielded wells of comparable performance to shot wells. To know that a formation is permeable or impermeable and that it carries oil is no longer enough to guide well completions.

FLUID BEHAVIOR IN SANDS

So much research, both in laboratories and in the field, has been done on the mechanism of the flow of fluids through porous media that it is difficult to choose for illustration a specific outstanding item. However, to illustrate the importance of what may at times appear to be almost academic research, remote from immediate practical application, studies of capillary pressures in sands afford an interesting example. Such studies indicated that capillary pressures are closely associated with the amount of connate or interstitial water held in producing formations, and led to the suggestion that an indirect means could be employed for the determination of connate water contents of cores. Recent comparisons of this indirect method with results obtained by coring with oil have indicated that the method has considerable promise.[6]

Connate water content of oil sands, like the shrinkage factor, is not merely a discount factor to be applied in reserve calculations, but may have a decided direct bearing on well productivity and the degree of oil recovery. Studies of secondary recovery operations have shown, for example, that under certain conditions excessive water content of an oil sand may make secondary water flooding impractical.[7]

WELL BEHAVIOR

Quantitative studies of producing formations and of the wells themselves are essential if wells are to be tested, completed, produced, and worked over at minimum expense. It is not sufficient to know that a well is a good or poor producer. The exact productivity factor, the productivity per pound pressure decline, and the relation between this factor and the capacity of the supposed producing interval provide important information on casing perforations, formation or screen plugging, cement seals, and other items having a direct bearing on the value of a well and its effectiveness in producing oil from a reservoir.

RESERVOIR BEHAVIOR

Quantitative interpretation of reservoir behavior has probably reached its highest development in water drive fields. During the war the net oil and water withdrawals from the East Texas field were so carefully controlled to maintain

[6] J. J. McCullough, F. W. Albaugh, and P. H. Jones, "Determination of Interstitial Water Content of Oil and Gas Sands by Laboratory Tests of Core Samples," *Amer. Petrol. Inst. Drilling and Production Practice* (1944), pp. 180–88.

[7] P. A. Dickey and R. B. Bossler, "Role of Connate Water in Secondary Recovery of Oil," in "Petroleum Development and Technology," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 155 (1944), pp. 175–83.

the reservoir pressure that although over 500 million barrels of oil were produced during the four years 1942–1945, inclusive, the reservoir pressure at the end of the period was substantially the same as at the beginning.

Many excellent papers have been written on the quantitative relationships between reservoir pressure decline and water influx. Under proper application, such relationships can be relied upon with confidence to predict the performance of water drive reservoirs over extended periods and to determine the effects of oil production rates and water injection or production on reservoir pressure. Similar techniques are being used extensively by the United States Geological Survey in evaluation of underground water supplies and their rates of availability.

An outstanding example of the utility of quantitative analysis of water drive reservoirs is furnished by the Midway field in Arkansas.[8] Calculations showed that the natural water drive in this field, while appreciable, was not adequate to support the desired rate of oil production. Further calculations showed that by supplementing the natural water drive with injected water the pressure could be maintained or even increased. It was possible to determine accurately the rate of water injection required to maintain any particular reservoir pressure at any particular rate of oil production. Based upon this quantitative analysis, the operators were able with confidence to evaluate in advance the results of water injection and to inaugurate a program of pressure maintenance. Subsequent results have demonstrated the accuracy of predictions made before start of the injection.[9] It is obvious that in this case the mere qualitative knowledge that the field had a water drive, good, fair, or poor, would have been inadequate information on which to base an operating program.

RESERVOIR SURROUNDINGS

The quantitative interrelationship beteen a petroleum reservoir and its surroundings is well illustrated by a study of various Smackover pools in southern Arkansas.[10] The behavior of these pools and their rates of water influx were quantitatively determined with the aid of an electric device for solving the mathematical relationships involved. These studies revealed that the pools must compete for the available water supply in the Smackover formation and that the pressure decline of one pool will affect the pressures of other pools in the same formation. It was shown, for example, that production from the Magnolia pool will have a greater effect on the reservoir pressure of the Village pool than will the production from the Village pool itself. Without a quantitative analysis of the

[8] W. L. Horner and D. R. Snow, "A New Application of Water Injection for Maintaining Pressure and Increasing Natural Water Drive," *Amer. Petrol. Inst. Drilling and Production Practice* (1943), pp. 28–34.

[9] W. L. Horner, "Pressure Maintenance by Water Injection, Midway Field, Arkansas," *Oil and Cas Journal*, Vol. 44, No. 28 (November 17, 1945), pp. 185–90.

[10] W. A. Bruce, "A Study of the Smackover Limestone Formation and the Reservoir Behavior of Its Oil and Condensate Pools," in "Petroleum Development and Technology," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 155 (1944), pp. 88–119.

entire Smackover producing region, misinterpretation of the pressure behavior of individual pools might have led to mistakes in operations.

Another example of the relationship of the behavior of a pool to its environment is afforded by the Hawkins pool in East Texas.[11] Measurements made at various points in the basin showed that the pressure in the Woodbine sand had been lowered to an appreciable extent over a considerable area prior to discovery of the Hawkins field. One segment of the Hawkins field was found upon discovery to have the same initial pressure as that then existing in the Woodbine sand. The major part of the field, however, was found at the time of its discovery still to have a pressure corresponding with the original pressure in the Woodbine sand, approximately 280 pounds per square inch greater than the actual pressure in the vicinity of the field at the time of discovery. The quantitative pressure measurements showed at an early stage in the development of the field that the major portion of the Hawkins reservoir is effectively sealed off from the water in the Woodbine sand and that, unlike all other Woodbine fields, the major portion of the Hawkins reservoir has no water drive. This conclusion could not have been reached without quantitative measurements.

PRESENT STATUS OF PRODUCTION TECHNOLOGY

It is not possible in a brief review of this sort to cover in detail all of the important developments in production technology. Those who are interested in the details may find ample coverage of various items in the technical literature. The following, however, summarizes the present status along certain lines of particular interest and importance.

The thermodynamic properties, phase relations, and physical behavior of the hydrocarbons comprising oil and gas mixtures and are now reasonably well understood both at high pressure and low pressure, and for condensate reservoirs as well as ordinary oil and gas reservoirs. Methods are in routine use for determination of the pertinent properties of such mixtures under reservoir temperature and pressure. The present state of development in this field is the result in part of excellent research sponsored cooperatively by the industry through the American Petroleum Institute and in part of research done directly by the industry. In this field of activity, guesswork is unnecessary. Both the methods and the technical understanding are available for providing quantitative answers to most of the problems which arise. For example, it is possible to determine accurately by appropriate test procedures whether a particular gas-liquid mixture exists in the reservoir as crude oil, as natural gas, or as a combination of both. If it is gas in the reservoir, it is possible to determine the extent to which condensation will occur in the reservoir with depletion and pressure decline, the composition of the condensing liquid, and the resultant changes in character and composition of the produced mixture.

[11] E. A. Wendlandt, T. H. Shelby, and John Bell, "Hawkins Field, Wood County, Texas," paper presented before the Association at Chicago, April 3, 1946.

The determination of formation characteristics is in a far less advanced state quantitatively, particularly from the standpoint of fluid content, than is the determination of the properties of the fluids. While determinations of porosity and permeability and to a lesser extent gas, oil, and water saturations are routine on cores, most wells are not cored and core recovery is frequently incomplete. Advances are being made in various logging techniques and interpretations and in control of drilling mud properties to reduce core flushing and contamination. The use of pressure measurements in connection with production and injection tests of wells is being used to an increasing extent to evaluate specific producing intervals.

The present state in this field must be described as only partly satisfactory. Progress is being made, however, through various lines of attack. Since the geologist is directly concerned with this problem, his active cooperation in its solution is required.

Excellent research has disclosed fairly completely the fundamental principles controlling the heterogeneous flow of oil, gas, and water in sands. This information is being applied quantitatively to well completions and to operation of both water drive and gas drive reservoirs. Such application is based on laboratory flow tests of selected cores and field measurements. Progress in this field is proceeding at a rapid rate. Much less is known of the mechanism of flow in limestones of different porosity types.

Advances in well completion, testing, and repair have been principally mechanical or semi-mechanical. Non-mechanical progress is dependent largely on further developments in evaluation of formation characteristics and fluid contents. Improved depth measurements, control of completion intervals, and isolation of selected horizons have advanced materially. The use of materials other than cement for exclusion of gas and water has progressed rapidly in some areas. Selective methods of testing and acidizing limited intervals are in use.

The identification and control of the type drive or recovery mechanism operative in a reservoir has reached a rather thorough state of quantitative development. In condensate reservoirs, gas drive, and water flooding operations electrical models are being employed extensively to disclose sweep patterns and to control input and production rates to obtain maximum flushing.

In water drive reservoirs, methods are now available and are being widely used for quantitative determination of the amount of water influx, its relationship to reservoir pressure, and the effects of oil production rates and water injection on reservoir pressure. A relatively recent advance in this field has been the development of an electrical analyzer for solving the necessary relationships without the tedium and the limitations of the difficult mathematics involved.

In water drive reservoirs, it is now possible through the same techniques employed in analyzing the water influx into a reservoir to take into account the effects of known structural or depositional features on the rate of water influx into a particular reservoir. The effects of a near-by fault, decreased formation

permeability around a field, formation pinchout, and limitations of size of the water-bearing portion of a producing formation on the water drive of a reservoir can be quantitatively determined or predicted. The electrical analyzer is a particularly useful device in this connection. This again is a technical region in which both the engineer and geologist must cooperate to provide the quantitative basic information required for intelligent exploitation. The regional geology is as important an element in the problem as are the producing conditions in a reservoir itself.

SIGNIFICANCE OF QUANTITATIVE TECHNICAL OBSERVATIONS

The various examples cited for illustration in the preceding discussions are not unusual; problems are being solved regularly by equivalent approaches. Further developments now under way along various lines will bring accelerated progress as the solution of one problem points the way to the solution of another. The significance of this trend may be summarized as follows:

1. As it becomes more widely recognized that methods and knowledge are available which will supply quantitative results, management will demand such results and will reject qualitative substitutes.

2. To keep pace with the technological progress under way and to contribute his part to its further advancement, the technologist will be forced to sharpen his physical and mathematical intuition and his powers of perception.

Quantitative technology in oil production requires an exact comprehension of the chemistry, physics, and mechanics of the oil recovery process. In these sciences quantities are expressed precisely; their language is largely mathematics. A statement or observation which lacks precision is of little scientific value or use. Thus, those who by habit are prone to adopt the purely descriptive approach must adapt themselves to the more difficult task of quantitative study. Those unable to change pace to meet the accelerated tempo of the immediate future face the same technical obsolescence that has overtaken artisans of other industries when their skills based on sight, taste, smell, or feel were displaced by scientific controls based upon precise measurements.

The technical problems involved in oil production can not be narrowly confined to any one branch of engineering or of science. The utmost skill of our engineers and geologists must be combined. It is to be hoped that the necessary cooperation will result from their common need of mutual support.

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LOWER MIDDLE ORDOVICIAN OF SOUTHWEST VIRGINIA AND NORTHEAST TENNESSEE*

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ABSTRACT

The lower middle Ordovician of southwest Virginia and northeast Tennessee may be divided into 29 lithologic and faunal units, many of which are remarkably persistent throughout the area. Important lithologic changes were largely attributed to the presence or absence of individual units in the section, while changes by lateral gradation were considered of importance only in restricted parts of the section and in somewhat localized areas. "Barrier" control of facies is well illustrated by the comparison of the limestones directly northwest and southeast of Clinch Mountain in Virginia.

The two median belts directly autochthonous to the Saltville thrust show the most complete sections, containing in some areas all of the lithologic and faunal units of the standard section of Tazewell County, Virginia. Evidence of a large hiatus was observed in the northwest belts of the Saltville autochthone, indicating northwestward convergence of some of the units. The sections southeast of Clinch Mountain (Saltville allochthone) are considerably thicker and more clastic than those northwest of Clinch Mountain. Limestones of the latter area thicken and become more clastic along the strike of the median belts from Virginia into Tennessee.

Detailed sections measured along seven belts were compared with the revised classification of Tazewell County, Virginia. The Blackford, Five Oaks, Lincolnshire, Thompson Valley (new), upper Peery, Benbolt, Wardell, Bowen, Witten, and Moccasin formations extend into northeast Tennessee. The Ward Cove (restricted), lower Peery, and Gratton formations largely disappear in southwest Virginia. The "Mosheim," "Holston," "Ottosee," and "Bays" should be discontinued as definite formational names. The further use in this area of such terms as Stones River group, Blount group, Murfreesboro limestone, and Lowville limestone is not recommended. The Lenoir limestone and Sevier shale were redefined to preserve their validity. The "Holston" marble of the Knoxville, Tennessee, area was assigned a new name.

The current classification of major boundaries in Virginia and Tennessee needs revision but should await further detailed comparisons with the standard sections.

INTRODUCTION

The lower middle Ordovician rocks of the Appalachian Valley of Virginia and Tennessee were classified in three groups, the Stones River, Blount, and Black River by Ulrich in 1911[1] (Table I), the first two considered partly equivalent to the Chazy formation of New York. The classification was associated with the interpretation that differing sections in several fault blocks had been laid in "troughs" separated by land or structurally higher "barriers." Although this interpretation has been questioned,[2] the essential features of the classification and interpretation have been maintained for many years.[3] Through the detailed mapping of 29 lithologic and faunal zones in Tazewell County, Virginia, several inconsistencies were recognized in the previous mapping.[4] Only through reclassification could a clear picture of the relations be shown.

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[1] E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. America*, Vol. 22 (1911), p. 608.

[2] P. E. Raymond, "Middle Ordovician of Virginia and Tennessee" (abstract), *Bull. Geol. Soc. America*, Vol. 31 (1920), p. 137.

[3] Charles Butts, "Geology of the Appalachian Valley in Virginia," *Virginia Geol. Survey Bull. 52* (1942), pp. 478–85.

In order to gain better understanding of the regional stratigraphy, the writer traced the newly classified units throughout the several fault blocks in southwest Virginia and northeast Tennessee. Sections were measured at intervals along the belts to determine the distribution and interrelations of the lithologic and faunal units, and to compare the formations of the revised classification with those of older usage.

The area investigated lies entirely within the Appalachian Valley and Ridge province. It extends along the Valley from Newcastle, Virginia, to Lenoir City,

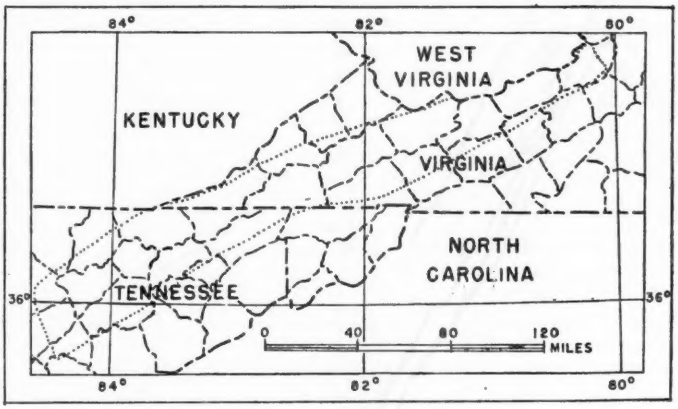

FIG. 1.—Index map showing location of area investigated.

Tennessee, and across the Valley from Clinch Mountain and the Saltville thrust to the Cumberland-Allegheny Front, where the Valley and Ridge province joins the Appalachian Plateau.

The field investigations were begun during the summer of 1941 and have continued at various intervals since that time. The work was conducted under the general supervision of Professor Marshall Kay of the Columbia University Department of Geology. The writer is indebted to Professors W. H. Bucher and C. H. Behre, Jr., also of that Department, for reviewing and helpfully criticizing the manuscript. The writer also benefited by discussions with Josiah Bridge of the United States Geological Survey, and G. A. Cooper, of the United States National Museum.

General Geology and Structure

The Ordovician limestones in this area form a part of the folded and faulted Paleozoic sediments of the Appalachian Valley. They crop out along several sub-

[4] B. N. Cooper and C. E. Prouty, "Stratigraphy of the Lower Middle Ordovician of Tazewell County, Virginia," *Bull. Geol. Soc. America*, Vol. 54 (1943), pp. 819–86.

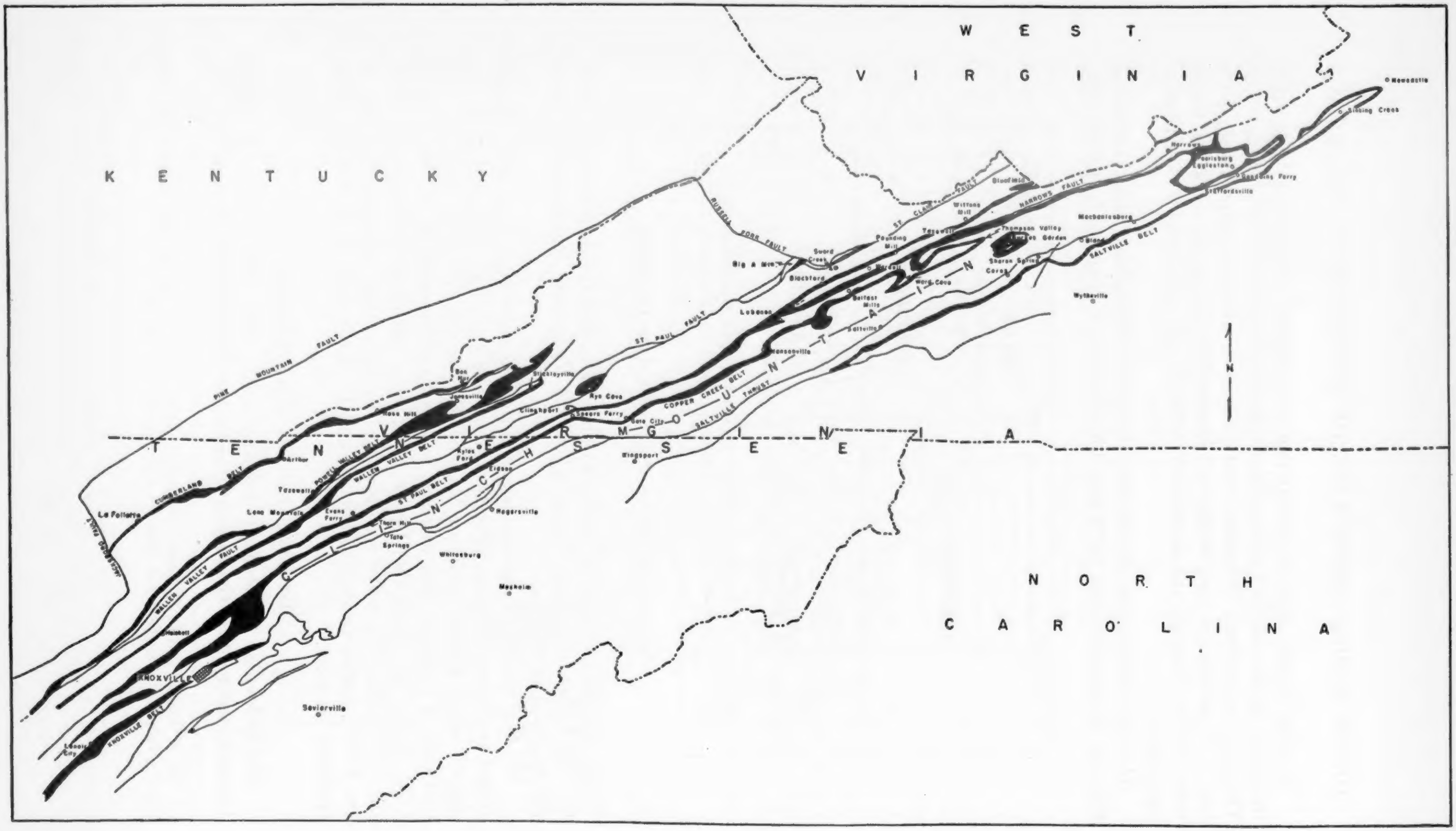

FIG. 2.—Distribution of lower middle Ordovician of median and northwest belts of southwest Virginia and northeast Tennessee.

parallel belts formed through repetition by faulting and folding. The traces of these belts are well shown on Butts' Valley map,[5] repeated with minor changes and additions in Figure 2. The rocks trend in general northeast and southwest, characteristic of the Valley and Ridge province, and dip northwest or southeast through all angles. In general the Canadian dolomites, and to some extent the middle Ordovician limestones, occur along the floors of the valleys, while Mohawkian limestones (Martinsburg formation) form the steep slopes of the ridges, and extend nearly to their crests, which are generally supported by resistant Silurian sandstones and sandy shales. A low shelf is commonly noticeable along the ridges at the Moccasin-Eggleston or Eggleston-Martinsburg contact formed through the differential weathering of the two formations.

The Saltville thrust, occurring along the southeast border of the entire area, forms the front of the Appalachian allochthone, and separates the thicker more typically geosynclinal sections on the southeast from the foreland sections on the northwest. Though most of the detailed work was done northwest of this line, the area immediately southeast was studied in sufficient detail to compare the two areas. The southernmost belt extends from Newcastle, Virginia, to the vicinity of Abingdon, Virginia, and is referred to merely for convenience in later discussions as the "Saltville belt." In Tennessee, the "Knoxville belt" is also directly allochthonous to the Saltville thrust and extends from Strawberry Plains through Knoxville to and beyond Lenoir City, the end of the area herein discussed (Fig. 2). The rocks are thicker and more coarsely clastic than those of the Saltville belt.

The first belt northwest of Clinch Mountain has an irregular pattern from north of Newport, Virginia, to northwest of Knoxville, Tennessee. It is folded at the northeast end into a broad doubly pitching anticline which has been breached by Walker Creek, exposing the older Cambrian and Ordovician dolomites and shales. The belt is terminated by the Narrows thrust along which the middle Ordovician limestones have been placed against Martinsburg limestones. Near Tazewell, Virginia, the belt divides and the southeast limb is folded into the plunging anticlines of Thompson Valley and Ward Cove. Burkes Garden, occurring just east of Thompson Valley, is an elliptically shaped structural dome which has been breached by Wolf Creek, exposing an inlier of Beekmantown dolomites in the center. The belt forms a part of the Copper Creek fault block from Belfast Mills, Virginia to the southwest and is referred to as the "Copper Creek belt." The limestones occur in a narrow belt about mid-way between the Copper Ridge thrust and Clinch Mountain and usually dip at steep angles southeast. At Hansonville, Virginia, a northwest-southeast cross fold flattens the beds locally into a broad belt.

Northwest of the Copper Creek belt the "St. Paul belt" may be traced from north of Narrows, Virginia, to and beyond Heiskell, Tennessee, in a narrow, quite linear belt. The southeastward-dipping limestones form a part of the St. Clair fault block from Narrows to near Honaker, Virginia. Here the fault joins the Honaker and St. Paul faults, the latter continuing southwest across Tennessee into Alabama. The St. Paul and St. Clair faults show considerable displacement, placing rocks as old as middle Cambrian against those of Mississippian and Pennsylvanian age. A few miles northeast of Clinchport, Virginia, Rye Cove represents an elongate structural basin with middle Ordovician limestones surrounded by Cambrian and lower Ordovician dolomites. The southeast and east portion of the Cove has been obliquely cut by the Clinchport fault, along which Rome sandstones and shales have been thrust against rocks of all ages within the Cove. Northeast of Clinchport, Virginia, only two small outcrops of middle Ordovician occur between the St. Paul belt and the Cumberland Front. These are at Big A Mountain[6] and Sword Creek.

Southwest of Clinchport, however, three additional belts occupy this interval. These occur in connection with the broad Powell Valley anticline, which forms a part of the Cumberland overthrust block.[7] The block was thrust along the Pine Mountain fault from near Jacksboro, Tennessee, to Rus-

[5] Charles Butts, "Geologic Map of the Appalachian Valley of Virginia with Explanatory Text," *Virginia Geol. Survey Bull. 42* (1933).

[6] R. L. Bates, "The Big A Mountain Area, Virginia," *Virginia Geol. Survey Bull. 46-M* (1936), pp. 167–204.

[7] J. L. Rich, "Mechanics of Low-Angle Overthrust Faulting as Illustrated by Cumberland Thrust Block, Virginia, Kentucky, and Tennessee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18 (1934), pp. 1584–96.

C. K. Wentworth, "Russell Fork Fault of Southwest Virginia," *Jour. Geol.*, Vol. 29, No. 4 (1921).

sell Creek, in Virginia. The fault block is bounded on the northeast by the Russell tear fault, which closely parallels Russell Creek to the Big A Mountain area where it joins the St. Paul (Hunter Valley) fault. The southwest end is bounded by the Jacksboro tear fault.

Northwest of the St. Paul belt, the "Wallen Valley belt" extends from northeast of Stickleyville, Virginia, to west of Maynardville, Tennessee, where the limestones end against the St. Paul fault. Near the former area the belt ends in a plunging anticline, the north part of which is cut by the Wallen Creek fault. The belt has been thrust northwestward along the latter fault, placing Cambrian dolomites against Ordovician and Silurian rocks of the southeast limb of Powell Valley anticline. The limestones dip southeastward at 25° to 35° and pass with normal sequence into the Silurian rocks supporting Powell Mountain and the Carboniferous rocks of Newman Ridge.

Occurring immediately northwest of the Wallen Valley fault, the middle Ordovician of the "Powell Valley belt" extends along the southeast flank of the Powell Valley anticline from about 4 miles southwest of Big Stone Gap, Virginia, to about 3 miles southwest of Tazewell, Tennessee. Southwest of the latter area the middle Ordovician disappears for about eight miles along the Wallen Creek fault but reappears and continues across Tennessee, passing near Clinton, Decatur, and Ooltewah. Near Jonesville, Virginia, the middle Ordovician limestones flatten into a broad, gently folded belt several miles in width. Near the northwest end of the belt, the limestones and the overlying rocks have been considerably cut by normal faulting which for the most part parallels the axis of the Powell Valley anticline. Butts[8] calls attention to the areas of local intense deformation near Ben Hur and Big Stone Gap and compares them with other local areas of possibly similar origin, as 3 or 4 miles southeast of Stickleyville, Virginia.

The "Cumberland belt" is the most northwesterly of the lower middle Ordovician belts and crops out along the northwest flank of the Powell Valley anticline from Dryden, Virginia, to 3 miles southwest of Jacksboro, Tennessee, where it ends against the Jacksboro tear fault. The limestones generally dip northwestward at steep angles into the Cumberland escarpment. The northeast end of the belt has been partly cut by normal faulting along the plunging nose of the Powell Valley anticline.

Classification in Virginia and Tennessee

The earlier classifications, chiefly that of Ulrich (Table I), were critically analysed throughout southwest Virginia and northeast Tennessee. The investiga-

TABLE I

Lower Middle Ordovician Classification for Southern Appalachian Valley After 1911 (Ulrich)

Mohawkian series	Black River group	Moccasin limestone Lowville limestone
Chazyan series	Blount group	Ottosee limestone Tellico sandstone Athens shale Whitesburg limestone Holston marble
	Stones River group	Lenoir limestone Mosheim limestone Murfreesboro limestone

tion indicated that erroneous formational designations were made mainly because of repetition in the section of similar lithologies; recurrence of a few "diagnostic" fossils; incorrect use of guide fossils; and insufficient data on type sections. The reclassification proposed for Tazewell County was applicable throughout a good portion of southwest Virginia and northeast Tennessee. Some re-

[8] Charles Butts, "Geology of the Appalachian Valley in Virginia," *Virginia Geol. Survey Bull. 52* (1942), p. 467.

grouping of the units became necessary, however, to better adjust the classification to observed field conditions. Two new formational names, the Thompson Valley limestone and Farragut limestone, were proposed. The Cliffield formation was raised to group status and the included members elevated to formational rank.

CLIFFIELD GROUP

The Cliffield[9] was proposed for zones 1 through 9, including the basal clastics to the top of the second calcilutite (Fig. 3). Though the Cliffield is composed of readily distinguishable units in most places, lateral gradation of these units into considerable thicknesses of uniform calcilutite occur elsewhere, as at St. Clair, Virginia.

Throughout southwest Virginia and northeast Tennessee local examples of gradation into course-grained limestones were observed in the pre-Benbolt beds, independent of the overlying Benbolt. In addition to this physical evidence for a hiatus between the Cliffield and Benbolt, further evidence may be inferred from the absence northwest of Clinch Mountain of the thick Tellico sandstone of the southeast belts.

The various units of the Cliffield, originally described as members, are persistent throughout much of the area studied. These units appear no less significant in rank than the post-Cliffield formations, and were accordingly raised to formational rank. The Cliffield would thus become a group.

BLACKFORD FORMATION

General character and fauna.—Butts proposed the term "Blackford facies of the Murfreesboro formation" for the basal clastics composed of redbeds, chert conglomerates, and gray shales overlying the Beekmantown dolomites at Blackford, Virginia. The name was retained as the basal formation of the Cliffield group. It is composed largely of red dolomitic and calcareous claystone (zone 1) containing dolomite and chert pebbles derived from the underlying Beekmantown dolomites. The overlying beds (zone 2) contain dull ash-gray, platy, calcareous shale while the upper beds (zone 3) consist of light gray, fine-grained limestone, containing interbedded dark gray to black chert, which breaks into rectangular blocks. This zone contains such fossils as ***Dinorthis*** cf. ***D. atavoides*** Willard, ***Leperditia fabulites*** (Conrad), and ***Calliops*** sp.

Distribution.—The Blackford is widely distributed throughout both Virginia and Tennessee. Due to the outstanding red and gray colors and the position directly overlying the Beekmantown dolomites, it is easily recognized. In the Saltville belt the basal clastics are questionably present in the southwest part of the belt but were observed at Mechanicsburg, Virginia. In the northeast portion of the belt blocky chert, presumably that of zone 3, was observed directly below the Five Oaks calcilutite.

In the Copper Creek belt northwest of Clinch Mountain the member is absent at Pearisburg. Near Gratton zone 1 alone is over 80 feet thick. In Burkes Garden the zone 2 shale is well exposed along Highway 78 about 1 mile southeast of Central Church. At Pounding Mill, Virginia, the thickness

[9] B. N. Cooper and C. E. Prouty, "Stratigraphy of the Lower Middle Ordovician of Tazewell County, Virginia," *Bull. Geol. Soc. America*, Vol. 54 (1943), p. 862.

of the red claystone is about 106 feet thick; the ash-gray shale 30; and the blocky chert zone 30 feet. Near Eidson, Tennessee, the Blackford is thin and southwest of here is essentially absent.

In the St. Paul belt the member shows the thickest average development, approaching 200 feet near Dickensonville, Virginia. In the Powell Valley belt along Yellow Branch, $5\frac{1}{2}$ miles southeast of Rose Hill, Lee County, Virginia, the red basal clastics are silty near the base, becoming more argil-

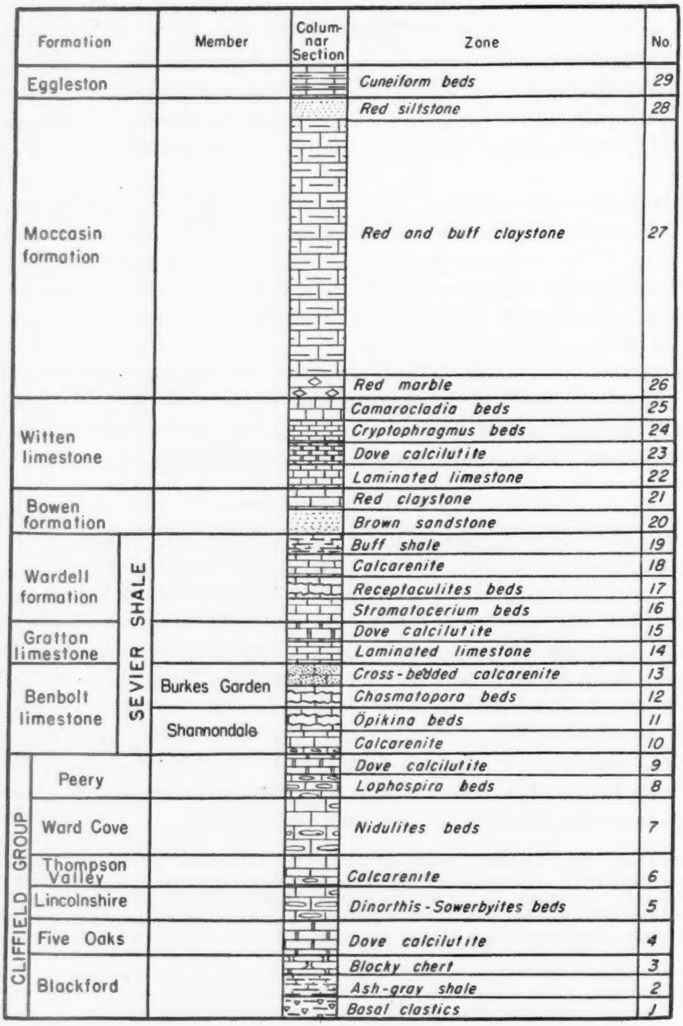

FIG. 3.—Generalized section of lower middle Ordovician formations in median and northwest belts of southwest Virginia and northeast Tennessee.

laceous toward the top. Alternations of red siltstone and gray silty claystone, more massive than typical zone 2 shale, occur near the base and it is indefinite whether this portion is upper Beekmantown or Blackford. A good exposure of the Blackford is along Highway 58, 7 miles east of Jonesville, Virginia (Table II).

TABLE II

SECTION THROUGH BLACKFORD FORMATION OF CLIFFIELD GROUP, 7 MILES EAST OF JONESVILLE, VIRGINIA

Description	*Thickness in Feet*	
	Of Unit	*To Base of Zone*
Cliffield group		
Blackford formation		
Zone 2		
Covered interval	18.0	152.5
Limestone, massive, light gray, argillaceous	12.0	134.5
Limestone, massive, gray, dolomitic	5.0	122.5
Limestone, massive, fairly pure, gray, fine	5.0	117.5
Claystone, grayish buff, shaly, silty	1.5	112.5
Limestone, slightly argillaceous, buff, dark to ash-gray, little chert at base	15.0	111.0
Claystone, buff	1.5	96.0
Limestone, gray, argillaceous	2.0	94.5
Clay, yellowish, almost pure	1.0	92.5
Claystone, very massive, calcareous, various shades of gray; breaks with smooth, almost conchoidal fracture; very dense	12.0	91.5
Shale, buff, few limy layers	5.0	79.5
Claystone, mixed gray and buff, shaly	21.0	74.5
Limestone, gray, shaly	9.0	53.5
Shale, limy beds alternating	5.0	44.5
Limestone, gray to buff; mostly well laminated	27.0	39.5
Covered interval	1.0	12.5
Limestone, massive, gray, argillaceous	1.5	11.5
Covered interval	10.0	10.0
Zone 1		
Claystone, very massive, gray and maroon mottled, becoming ash-gray at top	5.5	28.7
Claystone, red, gray and green mottled	10.6	23.2
Claystone, yellow and maroon mottled, sandy	9.5	12.6
Clay, yellowish green, sandy	0.1	3.1
Claystone, maroon	3.0	3.0
Beekmantown dolomite		

In this section the blocky chert of zone 3 is either absent or represented in the covered interval at the top. It appears to be transitional into the Five Oaks calcilutite in some places within this and other belts and in such cases the contact is indefinite. In the Cumberland belt the Blackford is missing in many places, as at La Follette and Shawanee, Tennessee. At Gully's Store, 2 miles west of Arthur, Tennessee, on Highway 63, the basal claystone contains large chert pebbles derived from the underlying Beekmantown dolomites. Much of the claystone here is buffish to light gray, rather than the typical maroon color. In this belt and parts of the Powell Valley belt, the ash-gray shale zone often becomes a massive, dolomitic claystone having a somewhat sucrose, mealy, appearance. Locally, in the absence of zone 1, there is an occasional transition from Beekmantown sucrose dolomite into the ash-gray zone. Above Beekmantown dolomite at Shawanee, Tennessee, there are several feet of calcilutite very similar to that of the Five Oaks limestone ("Mosheim" lithology), which underlie ash-gray sucrose claystone. Above the claystone occurs another calcilutite bed, containing traces of *Tetradium*. Above is a similar alternation. In this section it is not altogether clear where to place the upper Beekmantown boundary; also it is questionable whether to consider the intercalated calcilutites as an interfingering of the Five Oaks and ash-gray zone or a new development within the zone 2 ash-gray shales.

Correlation.—The Blackford is equivalent to Butts' "Blackford facies of the Murfreesboro." He has indicated the "Blackford facies" as representing the entire Murfreesboro in some sections.

FIVE OAKS LIMESTONE

General character and fauna.—The Five Oaks limestone is composed of a dove-gray calcilutite similar to limestone designated by Kindle[10] as "vaughanite" which term is often used in the Valley area. In many places the limestone is filled with "birdseyes" brought about by the weathering of calcite replacements of *Tetradium.* The lithology is similar to that of the Mosheim of Ulrich. The Five Oaks limestone was named for its occurrence near the village of Five Oaks, about 4 miles northeast of Tazewell, Virginia, where it is about 50 feet thick. It contains relatively few fossils, the more common being ***Tetradium syringoporoides*** Ulrich, ***Lophospira*** (several species), ***Hormotoma*** sp., ***Calliops*** sp., ***Homotelus*** sp., and ***Leperditia fabulites*** (Conrad).

Distribution.—The Five Oaks limestone is widespread and is represented in all the belts in southwest Virginia and northeast Tennessee. In the local absence of the Blackford, which is commonly missing in the areas of higher relief of the eroded Beekmantown surface, the Five Oaks lies directly on the Beekmantown dolomites. Just west of Newcastle and southwest of Goodwin's Ferry in the Saltville belt, the Five Oaks rests directly on the dolomites, while between these sections near Mechanicsburg the Blackford separates the Five Oaks from the dolomites. Butts[11] refers this calcilutite to the "Mosheim" and states that it generally overlies the Beekmantown in the area south of Clinch Mountain.

In the Copper Creek belt the Five Oaks is fairly persistent throughout though thin and locally absent. A pure limestone generally, it becomes dolomitic in places where directly overlying the Beekmantown, as just north of Gate City, Virginia, near the city limits along the road to Hill, Virginia. In the absence of the Blackford member, the dolomite and the calcilutite are intimately mixed as if transitional. In many places the gray to dove calcilutite becomes a dark gray to black, dense limestone, with chert commonly occurring near the bottom where the zone is closely associated with the blocky chert of the upper Blackford. The section about 2½ miles east of Tazewell, Virginia, just north of Mary's Chapel, shows these features (Table III).

Along the Virginian Railroad, 2 miles north of Narrows, Virginia, the Five Oaks member is only 9 feet thick. In the Peery Lime Company quarry just east of North Tazewell, Virginia, the zone is 125 feet thick, which represents about a maximum. Along Highway 25E, about 3 miles north of Thorn Hill, Tennessee, the zone is only a few feet thick and is separated from the Beekmantown by about 100 feet of Blackford. In the Knoxville belt the Five Oaks is equal to the "Mosheim" limestone and occurs directly on the Beekmantown. The zone occurs here and there between Knoxville and Lenoir City, in which latter place it directly underlies the type Lenoir limestone. The similarity of the Lenoir limestone and Lincolnshire limestone is discussed later.

In Rye Cove, the Five Oaks is well developed, attaining a thickness of 90 feet. The lower half lying directly on the Beekmantown is typical calcilutite, while the upper portion is filled with small yellow-stained cavities. This characteristic was not observed in any other section. In the Powell Valley belt, the zone is thin at Woodway and 2½ miles southeast of Jonesville, Virginia, but is absent to the southwest in the section 6 miles east of Tazewell, Tennessee, and at Sharps Chapel, Tennessee, where the much younger Gratton limestone rests on the Beekmantown. In the Cumberland belt the Five Oaks where present shows a transitional and occasional interfingering relationship with light gray dolomitic, argillaceous limestone, which may represent either reworked Beekmantown dolomites or, less likely, the ash-gray shales of zone 2 which have become dolomitized. The relationship is somewhat similar to the previously mentioned exposures just north of Gate City, Virginia. Just west of Ben Hur, Virginia, the zone shows a normal relationship to the overlying beds, whereas in the section along Highway 63, about 2 miles west of Arthur, Tennessee, at Gully's Store, the upper Wardell formation overlies. In the section just south of Shawanee, Tennessee, an even larger hiatus exists, with the Witten

[10] E. M. Kindle, "Nomenclature and Genetic Relations of Certain Calcareous Rocks," *Pan. Amer. Geol.*, Vol. 39 (1923), p. 370.

[11] Charles Butts, *op. cit.*, p. 135.

limestone lying on the Five Oaks. One mile west of La Follette, Tennessee, the Five Oaks member is missing and the Witten limestone lies directly on Beekmantown. The foregoing indicates a general northwest overlap of younger formations, finally culminating in the Cumberland belt, where the Witten overlies the lower Cliffield group in some places and Beekmantown dolomite in others (Fig. 7).

Correlation.—The Five Oaks represents the "Mosheim" limestone of some authors. The "Mosheim," however, has been referred to a higher calcilutite zone (Peery limestone) in many sections where only the latter of the two is exposed. Butts has generally referred the zone 4 (Five Oaks) calcilitute to the Mosheim where his "Blackford facies" represents the entire Murfreesboro. Where his

TABLE III

SECTION THROUGH LOWER CLIFFIELD GROUP, 2½ MILES EAST OF TAZEWELL, VIRGINIA

Description	Thickness in Feet	
	Of Unit	*To Base of Zone*
Cliffield group		
Lincolnshire limestone:		
Limestone, medium, bluish gray, argillaceous, cavernous; pitted surface	7.8	43.6
Limestone, medium-grained, non-cherty, thin-bedded, stylolitic	10.6	35.8
Limestone, bluish black, argillaceous, white-weathering chert	14.7	25.2
Limestone, light, dove-gray, fine-grained, wavy-bedded, abundant flecks and veinlets of calcite	1.7	10.5
Limestone, dark bluish gray, fine-grained, nodular, with black chert nodules	8.1	8.8
Limestone, coarse-grained, dark gray, saccharoidal	0.7	0.7
Five Oaks limestone:		
Calcilutite, dove-gray and light taupe-gray, mottled; abundant calcite veins and vugs	14.0	48.0
Limestone, dark bluish black, fine-grained	18.0	34.0
Calcilutite, dark bluish gray	16.0	16.0
Blackford formation:		
Limestone, thin-bedded, black, blocky chert, interbedded with gray calcilutite	40.0	60.0
Dolomite, thin-bedded, reddish, silty; containing pebbles of gray dolomite and white chert	20.0	20.0

Murfreesboro contains zones 1 through 8 (practically the entire Cliffield group) then zone 9 (Peery limestone) becomes his Mosheim, as in the Yellow Branch section, 5½ miles southeast of Rose Hill, Lee County, Virginia. It is here that Butts[12] showed to Ulrich's satisfaction at least that the upper calcilutite (zone 9) was the Mosheim and was post-Murfreesboro rather than pre-Murfreesboro as originally considered by Ulrich. The basis for this designation was the occurrence of a Murfreesboro-like fauna (zone 8) beneath the higher calcilutite. The Five Oaks, which is the Mosheim of Butts in the entire Saltville and Knoxville belts, and in various parts of the other belts northwest of Clinch Mountain, is also present in the Yellow Branch section beneath the Murfreesboro-like fauna.

In the typical Murfreesboro of the Central Basin of Tennessee, only the upper 70 feet of the formation is exposed. The fauna associated with *Polylopia billingsi*

[12] Charles Butts, *op. cit.*, p. 139.

there occurs low in the section. As this faunal zone is strikingly similar to that of the *Lophospira* beds (zone 8) of the Valley sequence, the Blackford, Five Oaks, Lincolnshire and Ward Cove seem to be older than the oldest exposed Murfreesboro in the Central Basin. Born[13] has described the unexposed portion of the Murfreesboro from well cuttings. His zone B consists of light gray to light tan calcilutite, showing "birdseye" (*Tetradium*) inclusions. According to Born[14] these beds are found interbedded with typical Murfreesboro in some places, and in others, as in Wells Creek Basin, are found interbedded with the sucrose dolomites of the underlying Knox dolomite. This sequence is strikingly similar to that described just south of Shawanee, Tennessee, where the Five Oaks member appears to be interbedded with sucrose dolomites of the Beekmantown, with the Blackford absent. The sections previously described at Woodway, Virginia, Jonesboro, Virginia, and Arthur, Tennessee, show similar sequences. Where the Five Oaks member directly overlies the Beekmantown and the interbedded calcilutites, it is difficult to draw the boundary. The presence of calcite "birdseyes" in the Five Oaks represent cross sections of *Tetradium syringoporoides*. The limestone interbedded in the sucrose dolomite did not show *Tetradium*. The similar lithology and stratigraphic position would at least suggest the contemporaneity of the Five Oaks and the zone B in the Central Basin. The Five Oaks limestone is probably equal to the "Mosheim" that underlies the Lenoir, thought by the writer to be largely equivalent to the Lincolnshire which overlies the Five Oaks in its type section.

LINCOLNSHIRE LIMESTONE

General character.—A dark bluish gray to brownish gray, medium-grained, irregularly bedded limestone averaging about 60 feet in thickness conformably overlies the Five Oaks calcilutite in Tazewell County, Virginia. The formation, named[15] for its occurrence along Lincolnshire Branch, one mile west of Five Oaks and about 3 miles northeast of Tazewell, Virginia, ordinarily shows nodular weathering, especially southwestward along the various belts. Black, lensy, chert nodules are ordinarily present.

Distribution and fauna.—One of the characteristic features of the Lincolnshire limestone is its tendency to assume a buff, nodular appearance on weathering. Even in the fresh rock, the wavy, clayey laminations, which on weathering accentuate the nodular tendency, may ordinarily be observed. Both the buffish color and nodular tendency become better developed southwestward from Virginia into Tennessee, and are accompanied by an increase in argillaceous content. The Lincolnshire contains *Sowerbyites triseptatus* (Willard), *Dinorthis atavoides* Willard, *Girvanella* sp., *Rostricellul* cf. *R. pristini* (Raymond), *Maclurites magnus* Lesueur, and a characteristic *Anthaspidella*-like sponge,[16] the latter two forms being much more prolific in Tennessee than in Virginia.

At Lenoir City, Tennessee, the type section of the Lenoir limestone, *Rostricellula pristina* (Raymond) is found abundantly at the base, forming practically a coquina above 0 to 50 feet of "Mosheim"

[13] Kendall E. Born, "Lower Ordovician Sand Zones ('St. Peter') in Middle Tennessee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), pp. 1641–42.

[14] Personal communication, 1942.

[15] B. N. Cooper and C. E. Prouty, *op. cit.*, p. 863.

[16] Charles Butts, *op. cit.*, Part II, p. 76, Figs. 32, 33.

calcilutite. This coquina zone disappears northeastward in Tennessee and Virginia, possibly as a result of the overlapping of the basal beds as the higher Lenoir beds appear to pass into the Lincolnshire. *Maclurites* was found generally to be most abundant where the limestone was most argillaceous. The southwestward increase in this form might reflect facies control.

In the Saltville belt south of Clinch Mountain, dark, cherty, slightly nodular limestones containing *Dinorthis*, *Maclurites*, and *Girvanella* were referred to the Lincolnshire. The zone is well developed near the northeast end of the belt, about 2 miles west of Newcastle, Virginia. Though present in the section at Goodwins Ferry and Mechanicsburg, the zone is questionably present at Sharon Springs.

In the Copper Creek belt the Lincolnshire becomes in part a light gray, coarsely crystalline limestone from near Belfast Mills, Virginia, to at least southwest of Eidson, Tennessee. In a section about 2½ miles east of Belfast Mills, Virginia, the lower portion is coarse and becomes fine and dense above, mixed with medium-grained, cherty limestone. At Hansonville, Virginia, southwest of Belfast Mills, the same relationship exists, the intermixed zone being overlain by the *Nidulites* zone. In Marcem Quarry, 2½ miles west of Gate City, Virginia, the light gray, coarsely crystalline zone replaces much of the typical Lincolnshire lithology. Farther southwest, about ½ mile north of Eidson, Tennessee, the same was observed except the proportion of coarse to fine is less than in Marcem Quarry. The Lincolnshire also assumed a more nodular and Lenoir-like appearance.

The Lincolnshire was not definitely recognized in the well exposed Thorn Hill, Tennessee section. Further study is needed here, however. The section is anomalous in that the entire pre-Moccasin sequence shows an exceptional development of coarsely crystalline beds. That this is a fairly local development rather than a general southwest gradation can be inferred from the resumption of the shaly character of the beds to the southwest. This does not apply to those zones normally calcarenitic, as they appear to maintain their coarsely crystalline lithology. Cooper,[17] however, considers the Blackford, Lincolnshire, Five Oaks, Ward Cove (including Thompson Valley), and Peery limestones to grade southwestward into 300 feet of "Holston" marble near Luttrell, Tennessee.

The writer believes the thickened "Holston" at Luttrell to represent the Thompson Valley limestone. This thickening is consistent with the general southwestward thickening of post-Cliffield beds, to be discussed later. The Lincolnshire as noted above, resembles the Lenoir facies at Eidson, Tennessee, and might well be referred to at least high Lenoir from here southwest. These beds, along with the Five Oaks and Blackford formations, are at least locally absent from near Thorn Hill to north of Luttrell, where the Lenoir reappears. It continues with increasing shale content to and beyond Fountain City, Tennessee. Due to the shaly nature of the beds and the deep weathering in this area, the only evidence for the formation at some places along the belt is the occurrence of shale chips in the soil between the "Holston" and the Beekmantown dolomite. Such an occurrence may be seen one mile west of the Knox County (Tennessee) Workhouse in a small exposure along the road-cut below the "Holston."

The place at which the Five Oaks limestone reappears along the belt is not definite. However, it was observed along the Mobry Hood road about 1½ miles north of the Knoxville-Lenoir City, Tennessee highway, U. S. Route 11 in a few small exposures. A few exceptionally well preserved fossils were found on the weathered surface of one of the exposures, including *Lophospira grandis* Butts, *L.* sp., *Helicotoma* cf. *H. tennesseensis*, *Omospira* sp., and *Lophonema* (?) sp. The Lenoir and "Holston" are well exposed above, the former containing *Maclurites magnus*, *Girvanella* sp., *Anthaspidella* sp. and dinorthid forms comparable with those in the Lincolnshire at Eidson, Tennessee.

In the Knoxville belt southeast of the Saltville thrust, a similar section occurs in the area of the type Lenoir limestone at Lenoir City, Tennessee. From Lenoir City, northeastward to and beyond Knoxville, the Lenoir occurs below the "Holston" and above the "Mosheim." The latter occurs sporadically, disappearing in the areas of high relief on the eroded Beekmantown surface. The upper portion of the Lenoir generally shows dark gray coarsely crystalline limestone similar lithologically to the coarse, interbedded limestones within the Lincolnshire of southwest Virginia. This zone has been occasionally quarried, passing under the trade name of "Chickamauga Black." This zone is easily distinguished from the light gray to pink "Holston" above.

In the St. Paul belt, in Virginia, the Lincolnshire becomes more coarsely crystalline southwestward to about Dickensonville where this feature shows about the maximum development. Here the finer beds contain *Dinorthis atavoides*, *Maclurites magnus*, *Girvanella* sp., and *Anthaspidella* sp. In the Evans Ferry section about 4 miles north of Thorn Hill, Tennessee, along U. S. Route 25 E, and 1 mile south of the old Evans Ferry across the Clinch River, beds somewhat transitional between Lincolnshire and Lenoir facies contain *Homotelus* cf. *H. elongatus* Raymond, *Dinorthis atavoides* Willard, and *Sowerbyites* cf. *S. triseptatus* (Willard). The upper beds are mixed fine and coarse, dark gray limestones directly underlying beds of light gray to pink "Holston"-like lithology.

The Lincolnshire thins northwestward and occurs only locally in the northwest belts. In Rye Cove, Virginia, the Lincolnshire is coarse and transitional with the overlying Thompson Valley

[17] B. N. Cooper, "Facies Variation in the Middle Ordovician of the Appalachian Valley in Virginia" (abstract), *Bull. Geol. Soc. America*, Vol. 55, No. 12 (1944).

limestone. A thin zone of dark, cherty, limestone similar to the Lincolnshire was observed at Glass Store, 4½ miles southeast of Jonesville, Virginia, and along Yellow Branch, 4½ miles southeast of Rose Hill, Virginia. In the absence of the Thompson Valley calcarenite, the contact between this unit and the overlying dark, cherty limestone of the Ward Cove (?) and Peery limestones was difficult to draw. At Ben Hur, Virginia, a few feet of limestone suggestive of gradational Lincolnshire and Thompson Valley were observed. No similar beds were found southwest of here in the Cumberland belt.

Correlation.—The Lincolnshire limestone of Tazewell County and southwest Virginia appears to have the same stratigraphic position and fairly close fauna to the higher Lenoir limestone of Tennessee. The Lincolnshire passes laterally into upper Lenoir-like lithology along the median belts. The type Lenoir and Lincolnshire are to be distinguished from the "Lenoir" as often mapped in Virginia, where it has been occasionally mistaken for the nodular Benbolt which also contains a *Maclurites* quite similar to *M. magnus*. This has been the case at the Yellow Branch section in Lee County and in Bluestone and Clear Fork valleys in Tazewell County, Virginia. Where the Blackford and Five Oaks were observed in the section, Butts often mapped the dark, cherty limestones overlying the Five Oaks ("Mosheim") as the Lenoir. This designation was apparently correct, but portions of the somewhat lithologically similar Ward Cove and lower Peery limestones were sometimes included in his Lenoir as in portions of Clinch Valley, a few miles northeast of Tazewell, Virginia.

THOMPSON VALLEY LIMESTONE (NEW)

Name and definition.—The Thompson Valley limestone is proposed for the thick-bedded, light gray, commonly variegated, coarse-grained limestone (calcarenite) originally referred to zone 6 of the Tazewell County classification. The original descriptions and type locality[18] of zone 6 would apply directly to the Thompson Valley limestone. The name was derived from Thompson Valley, Tazewell County, where the limestone is well developed. The zone was removed from the base of the Ward Cove formation, which is herein restricted to the *Nidulites* beds (zone 7). The classification of this zone as an individual unit was found more compatible with regional observations.

Distribution.—The Thompson Valley limestone is well developed in the median belts but occurs only locally in the northwest belts. In the Saltville belt beds similar to the Thompson Valley limestone are well exposed in the McNutt Quarry, 1½ miles southeast of Sharon Springs, Virginia (Table IV). Cooper[19] has recently referred the name Effna to these beds, restricting the term to the area southeast of Clinch Mountain. The Effna limestone is below the Whitesburg, Athens, and Peery limestones in the sequence southeast of the Saltville thrust. The Effna is thought to be partly equivalent to the Thompson Valley limestone but the relationships of the succeeding Whitesburg to the Thompson Valley and Ward Cove are uncertain. Because of this indefinite relationship the use of the two names Effna and Thompson Valley appears advisable.

The faunas from the above and near-by sections have been studied by Raymond[20] and Willard.[21]

[18] B. N. Cooper and C. E. Prouty, *op. cit.*, pp. 827, 863, and 894.

[19] B. N. Cooper, "Geology and Mineral Resources of the Burkes Garden Quadrangle, Virginia," *Virginia Geol. Survey Bull. 60* (1944), p. 59.

[20] P. E. Raymond, "Some Trilobites of the Lower Middle Ordovician of Eastern North America," *Harvard Coll., Mus. Comp. Zoology Bull.*, Vol. 66, No. 1 (1925), pp. 1–180.

[21] Bradford Willard, "The Brachiopods of the Ottosee and Holston Formations of Tennessee and Virginia," *ibid.*, Vol. 68, No. 6 (1928), pp. 255–92.

The few unbroken fossils that could be collected from the Thompson Valley northeast of Clinch Mountain compare favorably with those from McNutt Quarry and include *Oxoplecia holstonensis* Willard, *Dinorthis atavoides* Willard, *Solenopora* sp., *Acrolichas minganensis* (Billings), and *Hyboaspis* sp.

The beds directly below the calcarenite are questionably referred to the Lincolnshire. The Five Oaks and Blackford are thinnly developed below. Overlying the Thompson Valley at McNutt quarry

TABLE IV

SECTION THROUGH LOWER CLIFFIELD GROUP AT MCNUTT QUARRY, 1½ MILES SOUTHEAST OF SHARON SPRINGS, VIRGINIA

Description	*Thickness in Feet* Of Unit	*Thickness in Feet* To Bottom of Formation
Whitesburg limestone		
Limestone, irregularly bedded, nodular, gray, coarsely crystalline limestone, with intercalations of dense, black, compact limestone. Many bituminous partings, abundant trilobites	75.0	162.0
Covered interval	87.0	87.0
Effna limestone (partial equivalent of Thompson Valley)		
Limestone, light gray, uneven textured coarse and calcilutitic mixed	6.0	177.0
Limestone, uneven-bedded, grayish blue	13.0	171.0
Limestone, coarsely crystalline, gray with large trilobites	8.0	158.0
Limestone, medium to coarsely crystalline, light gray, containing algal masses and trilobites	5.5	150.0
Limestone, light gray to white, coarsely crystalline, many large trilobites	7.5	144.5
Limestone, uneven-textured, gray, with pinkish and greenish tinges. Many Illaenid type trilobites	22.0	137.0
Limestone, white, coarsely crystalline, coquinoid, with many trilobites, mostly of illaenid type. Fine-textured calcite preserves the fossils and gives uneven texture	115.0	115.0
Lincolnshire limestone		
Limestone, light gray, uneven-textured, fine-grained with coarse nests and stringers of calcite	23.0	51.0
Limestone, uneven-textured, large fragments of algal material	28.0	28.0
Five Oaks limestone		
Covered interval, containing light gray calcilutite and blocky, whitish weathering chert. (Five Oaks and Blackford contact concealed)	27.0	27.0
Blackford formation		
Siltstone, ash-gray, mealy, with few intercalations of gray dolomitic claystone	44.7	69.7
Claystone, gray, silty, with chert, and dolomite pebbles	8.3	25.0
Claystone, dolomitic, silty, containing angular pebbles of chert and sub-angular pebbles of dolomite	16.7	16.7
Beekmantown dolomite		

are dark gray slightly nodular-weathering limestones containing abundant trilobites and called Whitesburg by Butts.[22] In a near-by section (Table V), these beds underly dark, dense, argillaceous limestone containing Normanskill graptolites, which occur in the Athens formation in Virginia and Tennessee. These beds were found nearby to contain *Nidulites pyriformis* Bassler, which is found in the Ward Cove (restricted) northwest of Clinch Mountain, just above the Thompson Valley limestone. The partial equivalency of the Athens and Ward Cove, as previously suggested,[23] may be inferred from the presence in both of similar brachiopod and trilobite faunas. The graptolite fauna, however, is

[22] Charles Butts, field conference, 1940.

[23] B. N. Cooper, "Athens Equivalents Northwest of Clinch Mountain in Southwest Virginia" (abstract), *Bull. Geol. Soc. America*, Vol. 52, No. 12 (1941), p. 1892.

B. N. Cooper and C. E. Prouty, *op cit.*, p. 856.

conspicuously absent from the Ward Cove, northwest of Clinch Mountain. The Whitesburg, if present northwest of Clinch Mountain, would occur chronologically between the Thompson Valley limestone and the Ward Cove limestone (restricted), or be contained within them. The characteristic trilobite

TABLE V

SECTION THROUGH LOWER MIDDLE ORDOVICIAN, 2 MILES SOUTHWEST OF SHARON SPRING, VIRGINIA

Description	*Thickness in Feet*	
	Of Unit	*To Base of Zone*
Eggleston formation		
Moccasin formation		
Claystone, dark maroon, silty	245.0	297.5
Claystone, maroon, silty, highly fractured	25.0	52.5
Claystone, red and pale green, calcareous, with interbedded red or green calcilutite. Contains *Camarocladia* and *Lingula*	27.5	27.5
Witten limestone		
Limestone, partly covered interval. Fine-grained, unevenly calcilutitic with lenses of coarse-grained limestone. Contains *Tetradium*	147.0	147.0
Bowen formation absent		
Wardell and Gratton limestones absent		
Benbolt limestone		
Limestone, fine-to-medium-grained, gray, interbedded with coarse beds; both types nodular. Contains *Receptaculites*, *Echinosphaerites*, *Lichenaria*, and *Zygospira*	45.5	53.5
Limestone, gray, finely crystalline, nodular, containing *Lichenaria*, *Receptculitws*, *Pachydictya*, and *Strophomena*	8.0	8.0
Limestone, coarse-grained, light gray, weathering cobbly, fossiliferous	5.5	63.1
Limestone, coarse-grained	14.0	57.6
Limestone, coarse-grained, clastic, irregularly bedded, slightly cherty	27.0	43.6
Limestone, coarse-grained, clastic, fossiliferous	16.6	16.6
Cliffield group		
Peery limestone (Athens, in part ?)		
Limestone, dark gray, compact, nodular, fossiliferous	23.0	51.5
Limestone, dark gray, granular, argillaceous, containing wavy clay partings which give nodular appearance on weathering. Contains *Echinosphaerites*	22.5	28.5
Limestone, light gray, medium-grained, weathers nodular-forming characteristic gray, chalky residue	6.0	6.0
Athens limestone (partial Ward Cove equivalent)		
Limestone, very shaly; weathered buff	155.0	575.0
Limestone, fine-grained, compact, black, flaggy	58.0	420.0
Limestone, steel-gray to black, cobbly limestone, with black shale partings	78.0	362.0
Limestone, blocky to flaggy, compact, black; weather nodular; breaks with conchoidal fracture	17.0	284.0
Limestone, gray to black, cobbly, with black shale partings containing the graptolites. *Climacograptus* and *Didymograptus*	19.0	267.0
Limestone, flaggy, black, fine-grained, irregularly bedded; containing black, shale partings	52.0	248.0
Limestone, fine-grained, argillaceous, bluish black, bituminous shale partings, weathering cobbly. Few graptolites on the shale partings	50.0	196.0
Covered zone	146.0	146.0
Whitesburg limestone		

fauna and lithology of the Whitesburg[24] have never been reported in that area. The manner in which the Athens graptolite fauna and the Whitesburg trilobite fauna in Virginia and the Tellico in Tennessee abruptly disappear along the line of Clinch Mountain suggests a "barrier" of some nature to have existed in the approximate position of Clinch Mountain.

[24] E. O. Ulrich, "Ordovician Trilobites of the Family Telephidae and Concerned Stratigraphic Correlations," *Proc. U. S. Nat. Mus.*, Vol. 76 (1930), pp. 1–101.

Northeast of the McNutt Quarry in the Saltville belt the calcarenite thins to the end of the belt 2 miles west of Newcastle, Virginia. The overlying Whitesburg limestone apparently disappears before reaching Goodwins Ferry. The graptolite fauna of the Athens also disappears near here but the formation continues with little other change in fauna or lithology to the end of the belt. There, in the absence of the Whitesburg limestone and the graptolite fauna of the Athens, the pre-Benbolt section is practically identical faunally and lithologically with the pre-Benholt section northwest of Clinch Mountain.

In the latter area, the Thompson Valley limestone is developed throughout the Copper Creek and St. Paul belts. In the former belt, the zone is only a few feet thick at Staffordville but shows general southwest thickening, attaining a thickness of 75 feet in the type section in Tazewell County, Virginia, and about 250 to 300 feet in Fountain City, Tennessee. Throughout much of the belt the zone contains beds of dark gray, coarsely crystalline limestone not unlike the coarse beds commonly found in the Lincolnshire. In such instances the boundary between the two commonly becomes indefinite. This

TABLE VI

GENERALIZED SECTION OF LOWER MIDDLE ORDOVICIAN NEAR LENOIR CITY, TENNESSEE

Description	*Thickness in Feet*
Moccasin limestone	
Maroon, thin-bedded, argillaceous limestone, sandstone and claystone	1,110–1,300
Witten limestone	
Bluish gray, limestone; estimated thickness	50
Bowen formation	
Maroon claystone, containing 5–10 feet of gray, brownish-weathering sandstone near base; estimated thickness	200
Sevier formation	
Bluish gray, buffish weathering, calcareous shale with interbedded limestone, marble, and shaly limestone, about	1,100
Bluish gray, buffish weathering, interbedded limestone and shaly limestone	325
Gray to pink, oölitic, fossiliferous and shaly limestone, coarsely crystalline	225
Tellico formation	
Dark gray, cross-bedded, oölitic, stylolitic, sandy limestone	500– 650
Farragut limestone ("Holston" marble)	
Gray, pink and dark cedar, stylolitic, coarsely crystalline limestone or marble	250– 275
Lenoir limestone	
Bluish gray, thin-bedded, nodular, shaly limestone	250– 325
Five Oaks limestone ("Mosheim")	
Bluish gray calcilutite	0– 50
Beekmantown dolomite	

feature was especially noticeable between Gate City, Virginia, and Thorn Hill, Tennessee. The Thompson Valley underlies the Ward Cove throughout the Virginia portion of the Copper Creek belt. The typical Ward Cove-Peery fauna and lithology disappear in northeast Tennessee and in their absence the Thompson Valley directly underlies the Benbolt (lower Sevier).

South of the Saltville thrust in the Knoxville area, the "Holston' marble of the type area (Farragut limestone) is thought by the writer to be at least partly equivalent to the Thompson Valley limestone. This zone forms the principal marble quarried in the Knoxville region. The zone overlies the Lenoir (traceable into type Lenoir) and underlies the Tellico sandstone. The latter formation, which is confined to the Saltville allochthone, here separates the "Holston" from the Sevier (Table VI). Northwest of Clinch Mountain the Tellico is represented by an hiatus between the Thompson Valley and the Sevier in Tennessee; and probably between the Peery and Benbolt limestones in Virginia. As the Tellico does not occur in the same section with the Ward Cove and Peery limestones, their true relationships are uncertain.

The Thompson Valley occurs throughout the St. Paul belt from at least Springville, Virginia, to Halls Crossroads, Tennessee. The calcarenite does not usually show the typical light gray and variegated colors exhibited in the Copper Creek belt, but is commonly dark gray. The calcarenite is not unlike the coarsely crystalline beds occurring in the Lincolnshire and in many cases can be distinguished from the latter only through the dark, cherty limestone interbedded with the calcarenite of the Lincolnshire. It might be added that fossils of the Thompson Valley calcarenite are highly

fragmented and are not ordinarily available in sufficient quantity to be of much benefit in determining close contacts. However, the presence, in places, of *Oxoplecia holstonensis*, *Mimella* sp., *Schizambon* sp., and trilobite fragments of the *Illaenus*, *Bumastus*, and *Acrolichas* types, help to identify the formation.

The Thompson Valley is not ordinarily present in the northwest belts. A thin calcarenite bed thought to represent this horizon was identified at Woodway and Jonesville, Virginia, in the Powell Valley belt, and at Ben Hur, Virginia, in the Cumberland belt.

Correlation.—The Thompson Valley is equivalent to the "Holston" of Butts as recognized by him at Hansonville, Ward Cove, and Thompson Valley. Wherever he has referred the *Nidulites* beds of the Ward Cove to the "Ottosee," the underlying calcarenite (Thompson Valley) was called "Holston." The Thompson Valley is equal in part to both the Effna limestone of the Saltville belt between Walker and Brushy mountains, and to the Farragut limestone of the Knoxville belt.

FARRAGUT LIMESTONE (NEW; PARTIAL EQUIVALENT OF THOMPSON VALLEY)

Name and definition.—The Farragut limestone is proposed for the thick, coarsely crystalline variegated limestone, or marble, of the Knoxville, Tennessee, and surrounding area which overlies the Lenoir limestone (redefined) and underlies the Tellico sandstone. The zone has been referred to stratigraphically as the "Holston" marble in this area and represents the principal zone quarried for the commercial "Tennessee marble." Just east of Knoxville along the Holston River, Keith[25] assigned the name "Holston" to lentils of variegated marble occurring within the Chickamauga limestone. Since the term was originally assigned to a type of lithology occurring at different horizons the term "Holston" is of no significance as a definite formational unit and the term should be retained only in the marble industry where it is sometimes commercially used.

TABLE VII

TYPE SECTION OF FARRAGUT LIMESTONE, 1.4 MILES DUE EAST OF LOWES FERRY, TENNESSEE

Description	*Thickness in Feet*
Tellico "sandstone"	
Farragut limestone	
Limestone, argillaceous, buff, weathered	5.0
Limestone (marble), variegated, coarsely crystalline	6.0
Limestone (marble), dark cedar, coarsely crystalline	14.0
Limestone (marble), filled with fossil fragments	6.0
Limestone (marble), gray to light pink coarsely crystalline	77.0
Limestone (marble), gray to dark pink	7.0
Total	115.0
Lenoir limestone	

[25] Arthur Keith, *U. S. Geol. Survey Knoxville Folio 16* (1895), map.

The Farragut limestone was named for the site of the Admiral Farragut homestead at Lowes Ferry on the Tennessee River, 9.5 miles southwest of Knoxville, Tennessee. The type section, however, was taken from the Appalachian Marble Company quarry, 1.4 miles due east of the home site. The section in the quarry is given in Table VII.

General character and fauna.—The Farragut limestone is a variegated, coarsely crystalline rock composed largely of fossil fragments and calcite grains, essentially a calcarenite. The color varies from light gray through various shades of pink and brown to dark cedar. The limestone in places becomes argillaceous and in a number of places contains peculiar beds of fine, brownish red, reef-like masses of limestone, referred to in the marble industry as "Dolly Varden" marble.

The fossils are usually too fragmented to identify. A promising locality for collecting, however, was observed along Sheep Pen Bluff, across the Tennessee River and 1.2 miles southeast from the type section of the Farragut limestone, and 1.5 miles northwest of Louisville, Tennessee. Here were collected *Oxoplecia holstonensis* Willard, *Multicostella whitesburgensis* Butts, *Multicostella* sp., *Illaenus* cf. *I. fieldi* Raymond, *Leptellina* cf. *L. elegantula* (Butts), and *Schizambon* sp.

Distribution.—The Farragut limestone occurs throughout the Knoxville belt from near Tellico Plains, Tennessee, to and beyond Lenoir City, Tennessee. In the next belt southeast, it extends from about 6 miles northeast of Knoxville, where it ends against a thrust near Inman Branch, to South Knoxville and southwestward through the type section to and beyond Friendsville, Tennessee. In both belts the Farragut underlies the Tellico and overlies the Lenoir. The thickness is greater in the Knoxville belt than in the South Knoxville-Friendsville belt. In the former the limestone reaches 275 feet, but in the latter, it ordinarily does not exceed 125 feet.

Farther southeast the Farragut limestone disappears south of Bays Mountain. The younger Athens formation, which is represented in the Knoxville and South Knoxville (Vestal) belts by a hiatus between the Farragut and the Tellico, here occurs directly beneath the Tellico but in the absence of the Farragut, Lenoir, and Five Oaks ("Mosheim"), it overlies the Beekmantown dolomite.

Correlation.—The Farragut limestone has approximately the same lithology and to some extent fauna as the Thompson Valley and Effna limestones. Also all three occur above the Lenoir and Lincolnshire, considered to be at least partly synchronous. However, the Farragut is succeeded by the Tellico formation which has an uncertain relationship to the Ward Cove, overlying the Thompson Valley; and the Whitesburg, overlying the Effna.

The new fossils collected from upper Farragut limestone, 1.2 miles southwest of the type section, are strikingly similar to forms found in the type *Effna* limestone near Sharon Spring, Virginia. Forms such as *Oxoplecia holstonensis* Willard, *Illaenus fieldi* Raymond, *Acrolichas minganensis* (Billings), *Hyboaspis* sp., are common to the Thompson Valley and Effna limestones.

WARD COVE LIMESTONE (RESTRICTED)

Name and definition.—The Ward Cove as herein used is restricted to the *Nidulites* beds (zone 7) of the Tazewell County, Virginia, classification. All original descriptions, including the type section for this zone,[26] would remain the same for

[26] B. N. Cooper and C. E. Prouty, *op. cit.*, pp. 829–30.

Ward Cove, restricted. The Ward Cove takes its name from a breached plunging anticline occurring in the southwest part of Tazewell County, Virginia.

General character and fauna.—The Ward Cove is composed essentially of dark bluish gray, fine-grained limestone. It favors the Lincolnshire lithology somewhat but differs in its dense, compact texture and does not generally show the abundant black chert of the latter. The most outstanding fossil is the peculiar sponge *Nidulites pyriformis* Bassler. Other forms often observed include *Receptaculites* sp., *Sowerbyella delicatula* (Butts), *S. aequistriata* (Raymond), *Schizambon cuneatus* Willard, and species of *Homotelus* and *Remopleurides.*

Distribution.—The Ward Cove limestone is well developed in the southwest and median belts but occurs locally in the northwest belts. As mentioned earlier, the Ward Cove appears to be at least partly equal to the Athens limestone of the Saltville belt. The zone thickens southwest from about 150 feet, 2 miles west of Newcastle, Virginia, to over 350 feet at Mechanicsburg, and over 550 feet, 2 miles southwest of Sharon Spring, Virginia. Though the graptolites by which the Athens is generally identified disappear somewhat near Goodwins Ferry, Virginia, the typical *Nidulites* beds that otherwise contain the graptolites may be traced northeastward to the end of the belt, 2 miles west of Newcastle. There *Nidulites pyriformis* Bassler, *Echinosphaerites* cf. *E. aurantium* (Gyllenhal), *Receptaculites* sp., and numerous trilobite fragments belonging to *Calliops, Homotelus,* and *Hyboaspis* (?) were collected. In the absence of the graptolites, Butts[27] has referred these beds to the Lenoir limestone, which has somewhat similar lithology.

Northwest of Clinch Mountain, the Ward Cove of the Copper Creek belt reflects the northwest thinning of the formation, rarely exceeding 150 feet in thickness and averaging less than 100 feet. *Nidulites*, by which it is most readily identified, disappears a short distance northeast of Tazewell, Virginia, although the Ward Cove continues well into Giles County, Virginia. At Staffordville it is about 60 feet thick. Southwest of Tazewell, Virginia, the Ward Cove was recognized 2½ miles east of Belfast Mills, Virginia, where it contains a few coarsely crystalline beds. *Nidulites* was not found in this section nor at any point southwest of here. Directly south of Hansonville, Virginia, on the Abingdon road, U. S. Route 19 a small exposure of Ward Cove lithology was observed at the beginning of a long covered interval. The formation was not definitely recognized southwest of here and it apparently disappears in southwest Virginia or northeast Tennessee.

In the St. Paul belt the Ward Cove was recognized at least to Giles County, Virginia. Two miles north of Narrows, 60 feet of the beds were observed along the Virginian Railroad. The characteristic *Nidulites* was nowhere found along the belt from here to just east of Tazewell, Virginia. From Tazewell southwest to Lebanon, Virginia the forms are found in most exposures. They are present abundantly along U. S. Route 19 just south of the Russell-Tazewell County line. Only a few individual specimens were observed southwest of this point. Typical Ward Cove lithology disappears between Lebanon and Dickensonville, Virginia. At the latter place, much of the pre-Benbolt portion of the section shows intermixed coarsely crystalline beds. The Lincolnshire comprises most of the interval between the Five Oaks and Peery calcilutite, with the characteristic *Maclurites-Girvanella-Anthaspidella* assemblage occurring only a few feet below the latter. If the Ward Cove is represented it appears to be very thin. The development of coarsely crystalline limestone in this area is apparently local as the Evans Ferry, Tennessee, section shows only a few feet of beds of this nature at the top of typical Lincolnshire-Lenoir lithology. No beds containing typical Ward Cove or Peery lithology or fauna were observed.

The Ward Cove thins northwest, as well as southwest and west, and is ordinarily absent from the northwest belts (Fig. 7). A few feet of beds believed to represent the Ward Cove were found along Route 70, 2½ miles southeast of Jonesville, Virginia; at Woodway, Virginia; and along the road directly west of Ben Hur, Virginia.

Correlation.—The Ward Cove is equivalent to part of the "Ottosee" as often mapped by Ulrich and Butts. It is not the same as the type "Ottosee" however which is much younger. The Ward Cove has been so often mistaken for the "Ottosee" that the characteristic *Nidulites pyriformis* has been generally mistaken as a diagnostic fossil for the "Ottosee." The Ward Cove thins southwest-

[27] Charles Butts, "Geologic Map of the Appalachian Valley of Virginia," *Virginia Geol. Survey* (1933).

ward from Tazewell County, Virginia, and apparently disappears, being represented in east Tennessee probably by an hiatus between the Thompson Valley and Sevier, northwest of Clinch Mountain; and between the Farragut limestone and Tellico sandstone, southeast of Clinch Mountain. That the Ward Cove disappears entirely rather than changing facies to the southwest is further indicated by the presence near the top of the Farragut limestone in Tennessee of fossils closely comparable with those of the Effna limestone of Virginia, which is definitely pre-Ward Cove. This would leave little or no room for Ward Cove (or Peery) equivalents between the high fauna of the Farragut and the overlying Tellico formation.

The Ward Cove has similar stratigraphic position, lithology, and fauna to the Athens southeast of Clinch Mountain. The former differs mainly in the absence of the Athens graptolite fauna. It is likely that the Ward Cove is equal at least in part to the Athens formation. Its relationship to the Whitesburg limestone is uncertain.

PEERY LIMESTONE

General character.—The Peery limestone, named for the Peery Lime Company's quarry near State Highway 61, about $\frac{3}{4}$ mile east of the railroad station at North Tazewell, Virginia, consists of two distinct lithologic zones. The lower beds, zone 8, consist essentially of bluish gray to black dense, irregularly bedded limestones, commonly containing black chert. Bituminous clayey material ordinarily occurs along the irregular laminations and on weathering stands out in relief, giving a fluted appearance to the rock. Also on weathering the beds leave a residue of dull gray material, which has a characteristic chalky appearance. The zone is ordinarily about 40 feet thick in Tazewell County, Tennessee.

The upper beds, zone 9, consist of thick-bedded, dove-gray, calcite-flecked calcilutite, very similar to the Five Oaks calcilutite. The zone shows transitional relationship with the beds below. The unit is not persistent and in many places has been completely eroded away during post-Cliffield erosion. Owing to the similarity of the lithology to that of the "Mosheim" limestone, it has in places been mapped for that formation.

Fauna.—The lower Peery limestone is fossiliferous[28] containing predominantly a gastropod fauna largely composed of various species of *Lophospira*. The fauna is of particular significance in that it contains fossils similar to the Murfreesboro fauna of the Central Basin of Tennessee, including the rarely preserved pteropod, *Polylopia* (*Salterella*) *billingsi* (Safford).

The upper Peery calcilutite zone is fairly fossiliferous, containing mostly species of *Lophospira*. As in the Five Oaks calcilutite, the fossils ordinarily show only the etched outlines and rarely weather out whole.

Distribution.—The Peery limestone occurs in all the belts of this area, though only locally on the northwest. Post-Cliffield erosion removed the upper calcilutite zone in many places. In general

[28] B. N. Cooper and C. E. Prouty, *op. cit.*, p. 831.

the Peery limestone thins to the southwest of Tazewell County, Virginia, and apparently disappears in northeast Tennessee. Southeast of Clinch Mountain it is thinly developed in the northeast portion of the Saltville belt. The *Lophospira* beds are exceptionally well developed at the northeast end of the belt, attaining a thickness of more than 175 feet. The zone thins southwestward along the belt, averaging about 50 feet thick. The *Lophospira* zone shows maximum development in the northeast end of the Copper Creek belt near Staffordville, Virginia, where the zone reaches possibly 300 feet thick. Southwest along the belt the zone is traceable beyond Gate City, Virginia, to near the Tennessee state line. Directly southeast of Hansonville, Virginia, on the Abingdon highway, U. S. Route 19, a deeply weathered outcrop shows a number of *Lophospira* gastropods and also several specimens of the rarely preserved *Polylopia* (*Salterella*) *billingsi* (Safford). The calcilutite zone is best developed in the St. Paul belt, attaining a local thickness of more than 100 feet at Dickensonville, Virginia. It thins in a short distance southwest from this area and is present only locally throughout the Tennessee portion of the belt.

The Peery limestone occurs only locally in the northwest belts. About 2½ miles southeast of Jonesville, Virginia, the *Lophospira* beds are thinly developed. Along Yellow Branch, 5½ miles southwest of Rose Hill, Virginia, both zones of the Peery are present. The *Lophospira* beds of this section offer one of the best collecting localities for this zone. Butts[29] measured the section here and referred the *Lophospira* beds to the Murfreesboro formation and the upper Peery calcilutite to the "Mosheim" limestone. As has been earlier noted, the Five Oaks calcilutite, also of typical "Mosheim" lithology, occurs lower in this same section and probably represents the true "Mosheim."

The Peery limestone is mostly absent from the Cumberland belt. The lower Peery was found thinnly developed just west of Ben Hur, Virginia.

Correlation.—On the basis of faunal similarity, the lower Peery is correlated with at least part of the Murfreesboro limestone of the Central Basin area. In the latter area, the similar fauna occurs in the lowest exposed beds which according to drill records,[30] are about 215 feet above the base of the Murfreesboro. Inasmuch as the base of type Murfreesboro is unexposed, direct correlations can not be made.

The upper Peery calcilutite is equivalent to the "Mosheim" as mapped by Butts in such places as the quarry 1 mile east of Claypool Hill, Virginia, on U. S. Route 19; and in the Yellow Branch section. In such cases, he considered all beds between the "Mosheim" and Beekmantown dolomites to be of Murfreesboro age.

BENBOLT LIMESTONE

The Benbolt limestone[31] was named after an historic homestead just east of Tazewell, Virginia. The type section, however, was taken from the exposures at the Tazewell County Farm, 1.1 miles southwest of Benbolt and 1 mile southeast of Tazewell, Virginia. The formation is composed of two members which are similar lithologically but differ somewhat faunally.

SHANNONDALE LIMESTONE MEMBER

General character and fauna.—The lower member of the Benbolt, the Shannondale limestone,[32] was named for exposures occurring ¾ mile south of Shannondale, in Bluestone Valley, about 3 miles southwest of the city limits of Bluefield, Virginia, on the Bluefield-Tazewell highway, U. S. Route 19.

[29] Charles Butts, "Geology of the Appalachian Valley in Virginia," *Virginia Geol. Survey Bull.* 52 (1940), pp. 121, 122.

[30] K. E. Born, "Lower Ordovician Sand Zones ('St. Peter') in Middle Tennessee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 9 (1940), p. 1649.

[31] B. N. Cooper and C. E. Prouty, *op. cit.*, p. 869.

[32] *Ibid.*, p. 868.

The lower Shannondale, zone 10, has lithology comparable with the "Holston" (Farragut limestone) of Tennessee and has in places been mapped as such. The limestone is actually a calcarenite, composed of fossil fragments and calcite grains. The zone is fairly fossiliferous but, as in the case of the lower calcarenites fossils are commonly too fragmented to recover. *Camarella varians* Billings, *Camarotoechia quadriplicata* Willard, *Strophomena tennesseensis* Willard, and *Mimella melonica* (Willard) are occasionally recovered from the beds. The fauna is for the most part closely related to the upper Shannondale limestone.

The upper Shannondale, zone 11, is essentially a dark gray, buffish-weathering, nodular limestone. The unit is about 60 feet thick at Shannondale, Virginia. In Tazewell County, Virginia, the thickness varies from 5 feet to 100 feet in thickness. The most common fossils from this zone are *Strophemena tennesseensis* Willard, *Öpikina minnesotensis* (Winchell), *Ö. magna* Butts, *Mimella melonica* (Willard), *M. vulgaris* (Raymond), *Multicostella platys* (Billings), *Zygospira acutirostris* (Hall), and *Glyptorthis bellarugosa* (Conrad). A number of other forms occur less commonly in this member.[33]

BURKES GARDEN LIMESTONE MEMBER

General character and fauna.—The Burkes Garden member[34] was named for Burkes Garden Creek about 1 mile northwest of the Burkes Garden, Virginia, post-office.

The Burkes Garden member is composed of two types of lithology. The lower unit, zone 12, is a nodular limestone similar to the *Öpikina* beds on which it rests conformably. The two zones may ordinarily be differentiated faunally by the abundance of "*Chasmatopora*" (*Subretopora*) in zone 12. The latter is fossiliferous[35] containing several forms found in the Shannondale member.

The upper part of the Burkes Garden member, zone 13, is a coarse-grained gray, commonly cherty, cross-bedded limestone. Much of the zone is light gray and pinkish, closely resembling the "Holston" of Tennessee. A black chert bed occurs persistently near the top of the zone and serves as a good stratigraphic marker. The fauna of zone 13 is essentially the same as that of zone 12, with *Girvanella, Solenopora, Graptodictya,* and crinoid stems being particularly common. The thickness of the Burkes Garden member is 100 to 200 feet in the type area, but is thinner in the surrounding area.

Distribution.—Though the Shannondale and Burkes Garden members may be readily separated in Tazewell County, zones 11 and 12 become more shaly farther southwest along the belts and their separation in the field becomes more difficult. In such places it is probably not best to attempt differentiation and they should be mapped as a unit under the Benbolt limestone. The distribution of the Benbolt, therefore, is discussed as a unit with separation of units 11 and 12 only where practical.

The Benbolt has its best development in the Copper Creek and St. Paul belts and appears to thin both southeast and northwest from these belts. In the Saltville belt the formation is commonly absent. Just south of Goodwins Ferry, however, the Shannondale and Burkes Garden members are

[33] *Ibid.*, p. 870.

[34] *Ibid.*, p. 869.

[35] *Ibid.*, p. 835.

both present along the Virginian Railroad. Zones 10 and 13, however, appear to be absent from the section.

The Benbolt occurs throughout the entire Copper Creek belt. At the northeast end, the lower Shannondale is missing, and zone 11 overlies the Peery limestone. Zones 11 and 12 are not readily distinguishable but the tendency is for the Shannondale portion to be more nodular. *Öpikina minnesotensis* (Winchell) is common in the latter. The total thickness of zones 11 and 12 is about 115 feet, and is overlain by about 7 feet of the cross-bedded upper Burkes Garden. The coarse limestone of zone 10 occurs in places between Pearisburg and Tazewell, Virginia. In the section along Plum Creek, 3 miles southwest of Tazewell on the Thompson Valley road, the lower Shannondale member is absent but the upper Burkes Garden member has considerably thickened (Table VIII).

In Thompson Valley the Benbolt thickens to about 200 feet with the Burkes Garden member being over 100 feet. The lower Shannondale limestone is close to 75 feet thick. In Ward Cove, the Shannondale and Burkes Garden members cannot be easily distinguished and as both become more argillaceous to the southwest the contact becomes more indefinite and differentiation of the Benbolt becomes impractical. At Hansonville, Virginia, the lower Benbolt calcarenite is over 100 feet thick. At Marcem Quarry, west of Gate City, Virginia, the nodular Benbolt is well exposed south of the quarry where numerous "*Chasmatopora*" (*Subretopora*) sp., *Öpikina minnesotensis* (Winchell), and *Ö. magna* (Butts) may be found.

The Benbolt is well exposed along the Gate City-Speers Ferry, Virginia, road at Danlboone Station and at Speers Ferry, Virginia. Here the upper Benbolt is represented by about 60 feet of zone 13. The Gratton limestone is absent and the nodular Wardell lies directly above the Benbolt, giving the appearance of continuous Benbolt. Ulrich[36] here referred the nodular Benbolt and Wardell to the "Heiskell" shale which name was derived from rocks of similar nature at Heiskell, Tennessee, a few miles northwest of Knoxville, Tennessee.

The Benbolt, as will be shown later, appears to be equivalent to the lower "Ottosee" (Sevier) of Tennessee. The nodular beds which comprise the Benbolt in the Speers Ferry region were previously considered Ottosee by both Ulrich and Butts[37] though more recently Ulrich considered the fauna to be younger than Ottosee. In parts of Tazewell and Russell counties the *Nidulites* beds of the much older Ward Cove limestone were called "Ottosee" by both Butts[38] and Ulrich, as for examples in Ward Cove opposite the Al Gillespie farm, just south of County Road 604; and in the section along U. S. Route 19, at the Russell-Tazewell County line. In the latter area the *Nidulites* beds (which often assume a nodular appearance much like typical "Ottosee" of Tennessee) were called "Ottosee" and the underlying Thompson Valley calcarenite was referred to the "Holston." The sequence at Speers Ferry is similar lithologically to the nodular Benbolt and the underlying calcarenite of zone 10. It is easily understood how the calcarenite and nodular beds of the Benbolt could be confused lithologically with those of the Ward Cove. It becomes likewise apparent why the nodular beds at Speers Feery (Benbolt and younger) were considered by Ulrich younger than the "Ottosee" since his "Ottosee" in this area was confused with the older Ward Cove.

In the Thorn Hill, Tennessee section, Hall and Amick[39] assigned the coarse beds of zone 10 to their unit 716, considering it basal Lenoir. Units 717–718 of their Lenoir represent the Benbolt nodular beds, containing several large *Öpikina*. Units 719–721 of their Lenoir and 722–743 of their Holston represent the upper Benbolt or zone 13 coarse. This is overlain by 18 feet of calcilutite containing *Stromatocerium* cf. *S. rugosum* which might represent upper Gratton and lower Wardell. This zone is located in the interval between their units 743 and 744. Zone 13 in this section attains the exceptional thickness of about 150 feet. The zone is ordinarily 50 feet thick or less from Tazewell County to near Gate City, Virginia, but thickens southwest from Gate City to more than 100 feet at Eidson, Tennessee. It also loses most of its cross-bedded nature and becomes similar to the Tennessee "Holston" at Thorn Hill and Eidson, Tennessee; and Dickensonville, Virginia, where much of the limestone is pinkish and reddish and very coarsely crystalline. In these sections it is difficult to draw the contact between zones 12 and 13 due to the transitional nature of the nodular and crystalline beds. Zone 13 of the Thorn Hill section represents, along with zones 6 and 10, the third distinct horizon which has been referred to the "Holston" in the previous work of southeast Virginia and northeast Tennessee. Southwest along the belt the Benbolt nodular beds become more argillaceous and the proportion of shale to nodular limestone increases. The *Öpikina minnesotensis*, *Ö. magna*, "*Chasmatopora*" beds continue into the Knoxville area where they occur in the lower portion of the type "Ottosee" in Chilhowee Park, Tennessee. In the Fountain City, Tennessee, area the Benbolt,

[36] E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. Amer.*, Vol. 22 (1911), Pl. 7.

[37] Charles Butts, personal communication, 1940.

[38] *Idem.*, field conference, 1940.

[39] George M. Hall and H. C. Amick, "The Section on the West Side of Clinch Mountain, Tennessee," *Jour. Tennessee Acad. Sci.*, Vol. IX, No. 2 (1934), pp. 214–17.

lower Sevier, lies on "Holston"-like lithology thought to represent the Thompson Valley limestone, on the basis of *Oxoplecia holstonensis*. It is possible that the upper part of this zone contains coarse beds of the lower Benbolt but they would be difficult to distinguish because of the similarity in lithology.

In the Knoxville-Lenoir City belt, just southeast of the Saltville thrust, the Farragut limestone has much the same lithology, fauna and basal relationship as the Thompson Valley limestone at

TABLE VIII

SECTION THROUGH CLIFFIELD GROUP AND BENBOLT FORMATION ALONG TAZEWELL-THOMPSON VALLEY ROAD, 3 MILES SOUTHWEST OF TAZEWELL, VIRGINIA

Description	*Thickness in Feet* — *Of Unit*	*Thickness in Feet* — *To Bottom of Formation*
Witten limestone		
Benbolt limestone		
Burkes Garden member		
Limestone, coarse-grained, brownish gray, with intersecting clay partings. Few beds of coarse-grained, thin-bedded limestone near the middle of unit. Contains *Camarotoechia* cf. *C. plena* and orthid brachiopods	38	124
Limestone, gray, coarse-grained, cross-bedded, uneven texture	12	86
Limestone, dark gray, laminated, medium-grained and compact, argillaceous laminations which weather buffish	7	74
Shannondale member		
Covered interval	39	67
Limestone, very nodular, argillaceous, dark gray, abundant *Öpikina minnesotensis*	28	28
Peery limestone		
Calcilutite, dove-gray, containing etched, medium-spired gastropods	12	110
Limestone, light gray, even-grained, granular, non-cherty, stylolitic	9	98
Limestone, dark gray, fine-grained, even-textured, with few clay partings	40	89
Limestone, light gray, even-textured, medium-grained, very cherty with argillaceous partings	27	49
Limestone, light gray, fine-grained, uneven-textured, nodular; weathers chalky	22	22
Ward Cove limestone		
Limestone, dark to dove-gray, argillaceous, nodular; with sparse chert. Few *Nidulites*	55	179
Limestone, fine-grained, dark gray	11	124
Limestone, fine-grained, cherty, brownish black; bituminous partings. Few *Nidulites*	80	113
Limestone, medium- to coarse-grained, cobbly, cherty, light gray, mottled	12	33
Limestone, brownish black, very cherty, highly nodular, fine-grained, with abundant *Receptaculites*	21	21
Thompson Valley limestone		
Limestone, coarse-grained, gray with pinkish tinge, clastic texture	40	40
Lincolnshire limestone		
Limestone, medium-grained with fine-grained inclusions, many byrozoans; brownish black, weathers nodular, very cherty	22	99
Limestone, black, nodular, cherty	8	77
Limestone, brownish black, fine-grained, with argillaceous and nodular partings, abundant black chert	8	69
Limestone, gray, medium-grained, nodular, cherty, many bryozoans	61	61
Blackford formation		
Limestone, dark gray, with whitish-weathering, black chert. Contains *Dinorthis quadriplicata* and *Leperditia fabulites*	50	50
Beekmantown dolomite		

Fountain City, Tennessee. The former limestone is separated from the lower Benbolt (Sevier) coarse by the Tellico sandstone. Gordon[40] assigned the name Vestal limestone to the lentil of red limestone or marble occurring at or near the base of the Ottosee (Sevier), deriving the name from Vestal, Tennessee, just across the Tennessee River from Knoxville, Tennessee. This zone is widespread throughout the various belts southeast of Clinch Mountain in Tennessee. It thickens and thins in a short distance along the strike of the belt, varying from zero to more than 100 feet in short distances. The bed has been locally quarried in several places, notably at Meadow, Tennessee. Gordon[41] here assigned the name Meadow marble to the zone but thought it occurred within the Tellico and not the Sevier. The writer believes that the Vestal and the Meadow marble are the same and that they most likely represent a continuation of zone 10 of the lower Benbolt, which has the same stratigraphic position.

In Chilhowee Park, north Knoxville, Ulrich[42] assigned the name "Ottosee," though without definition, to beds identical with the Sevier shale. Presumably the name was proposed to replace the Sevier because of the misidentification of that formation in previous mapping. In Chilhowee Park the sequence is essentially the same as at Lenoir City, Tennessee (Table VI), differing mainly in the greater thickness of the Tellico sandstone in the latter area. Due to limited exposures and folding of the type "Ottosee," a good detailed section could not be obtained. The lower "Ottosee" contains abundant *Öpikina magna* (Butts), *Ö. minnesotensis* (Winchell), "*Chasmatopora*" (*Subretopora*) sp. *Batostoma sevieri* Bassler, and other less common forms of the upper Benbolt nodular, zone 12, of Virginia. Near the top of the exposed section, coarsely crystalline beds are mixed with a few feet of dove and pinkish calcilutite. The beds may represent an interbedding of the upper Benbolt and thin Gratton calcilutite, similar to that observed in the Thorn Hill section. The remainder of the section up to the Moccasin is largely covered, though local exposures reveal buff shaly limestone of the "Ottosee" (Sevier) type throughout the entire interval. This zone is largely equivalent to the Wardell formation of Virginia. The upper "Ottosee" is only slightly fossiliferous in this area but may be traced northeastward along the Copper Creek belt into fossiliferous Wardell beds in the Thorn Hill section.

The Benbolt limestone is well developed in the St. Paul belt from Narrows, Virginia, southwest to and beyond Heiskell, Tennessee. The beds show essentially the same changes noted in the Copper Creek belt to the southeast, showing considerable thickening and becoming more argillaceous in parts of the section. Near Narrows, Virginia, at the northeast end of the belt the Benbolt is 66 feet thick (Table IX). The zone 10 calcarenite is thin but thickens southwestward along with the nodular beds of zones 11 and 12. At Dickensonville, Virginia, the calcarenite is over 200 feet thick. Zone 13 has largely lost the cross-bedding so characteristic in Tazewell County and has assumed a pink and gray color similar to the zone at Eidson and Thorn Hill, Tennessee. It appears to grade into the "*Chasmatopora*" and *Öpikina* beds below and it is difficult to draw the exact boundary in such cases. In the Evans Ferry section the *Öpikina* and "*Chasmatopora*" beds are well exposed and are about 275 feet thick and the total Benbolt about 450 feet thick. At Heiskell, Tennessee, Ulrich[43] assigned the name "Heiskell," though without definition, to beds which there presumably contain the Benbolt and Wardell formation. In the absence of the Gratton calcilutite, the Benbolt and Wardell formations are essentially inseparable lithologically.

The "Ottosee" of Rye Cove, Virginia, is largely Benbolt in age. Numerous fossils may be collected from the nodular beds along the road cut just north of Rye Cove community on County Road 652, including such common forms as *Batostoma sevieri* Bassler, *Öpikina magna* (Butts), *Ö. minnesotensis* (Winchell), "*Chasmatopora*" sp., *Sowerbyella aequistriatus* (Willard), and *Glyptorthis bellarugosa* (Conrad).

In the belt from Stickleyville, Virginia, southwest to and beyond Glass Store, Virginia, the Benbolt is between 150 and 200 feet thick. At Stickleyville the lower Benbolt calcarenite is only about 1 foot thick and lies directly on the Five Oaks calcilutite, with practically the entire Cliffield group missing. The upper Benbolt contains about 50 feet of zone 13 containing a small amount of black chert at the top, often observed at this horizon in southwest Virginia. At Glass Store, 4½ miles southeast of Jonesville, Virginia, the section is similar. The Gratton limestone, which overlies the Benbolt at Stickleyville, however, appears to be absent here and the *Stromatocerium* zone of the Wardell is intermixed with zone 13.

The Benbolt is generally absent in the Powell Valley and Cumberland belts where higher limestones (mostly Gratton and Witten) have overlapped the Benbolt and upper Cliffield and overly the lower Cliffield or Beekmantown dolomites.

[40] C. H. Gordon, "Marble Deposits of East Tennessee," *Tennessee Div. Geol. Bull. 28* (1924), p. 35.

[41] C. H. Gordon, *op. cit.*, pp. 39-40.

[42] E. O. Ulrich, *op. cit.*, pp. 453, 551, 555.

[43] E. O. Ulrich, *op. cit.*

Correlation.—The Benbolt limestone is equivalent to the lower part of Ulrich's "Ottosee." At the type section of Ottosee in Chilhowee Park, Knoxville, Tennessee, it equals that portion lying between the Tellico sandstone at the base and probably the coarse and calcilutitic transitional zone occurring near the Beaman Street entrance to the park. This zone would appear to represent the Gratton-Benbolt contact. Where the Gratton is absent, which is commonly the case in Tennessee, the contact between the Benbolt and Wardell can not be accurately drawn and the two should best be combined under the Sevier formation as later defined. As the Sevier and Ottosee shale are presumably the same, the Benbolt would have the same relationship to it as to the "Ottosee." The type "Heiskell" appears to be part Benbolt and part Wardell. Ulrich did not define the Heiskell, and the upper and lower limits can not be definitely drawn. His application of the Heiskell at Speers Ferry, Virginia, indicates the lower limit to be the "Holston" (or zone 10 at Speers Ferry) and the upper limit to be the Bays (Moccasin). As the Bowen formation contains red claystone like the Moccasin claystone, his basal Moccasin was most likely drawn below the Bowen which would then make the "Heiskell" equivalent to all the Benbolt, Gratton, and Wardell.

The Benbolt is similar faunally to the Ridley limestone of central Tennessee and is probably at least partly equivalent to that formation.

The Hostler member[44] of the Hatter formation of central Pennsylvania contains the widespread *Öpikina magna*, *Ö. minnesotensis* and "*Chasmatopora*" (*Subretopora*) sp., fauna of the Benbolt. The nodular nature of the Hostler is suggestive of the Benbolt lithology. The upper Hatter is slightly cross-bedded, coarse-grained limestones at the same stratigraphic position as the zone 13 of the Benbolt.

GRATTON LIMESTONE

General character and fauna.—The Gratton limestone[45] takes its name from the community of that name, about 5 miles east of Tazewell, Virginia, in Clear Fork Valley. The type section, however, was selected from the exposures at the Tazewell County Farm, 1 mile southeast of Tazewell, Virginia. The Gratton is lithologically very similar to the Five Oaks and upper Peery limestone, being essentially a calcilutite. The lower part commonly has clay laminations which weather buff and yield a very characteristic and easily recognized unit. The thickness of the Gratton rarely exceeds 100 feet in the Tazewell area and it usually is much thinner.

The most outstanding fossils of the Gratton include *Tetradium cellulosum* (Hall), *T. racemosum* Raymond, and *Stromatocerium rugosum* Hall. *Cryptophragmus antiquatus* Raymond was found rarely.

[44] G. M. Kay, "Chemical Lime in Central Pennsylvania," *Econ. Geol.*, Vol. 38 (1943), p. 143.
———, "Middle Ordovician of Central Pennsylvania," *Jour. Geol.*, Vol. 52 (1944), p. 13.

[45] B. N. Cooper and C. E. Prouty, *op. cit.*, pp. 836–37, 872–73.

Distribution.—The Gratton limestone was not recognized in the Saltville belt, southeast of Clinch Mountain. In the Copper Creek belt the zone was found in most sections from Pearisburg, Virginia, to at least Thorn Hill, Tennessee. At Pearisburg, the lower laminated zone is about 25 feet thick and forms about half of the entire interval. The laminated zone thins southwestward along the belt, occurring only locally southwest of Tazewell County, Virginia. The Gratton is locally absent in Marcem Quarry west of Gate City, Virginia, where the Wardell nodular rests directly on the cross-bedded zone 13 of the Benbolt. In the Thorn Hill section the Gratton is about 18 feet thick and contains *Stromatocerium rugosum*.

The Gratton is somewhat better developed in the St. Paul belt and can be traced along the belt well into Tennessee. As in the case of the Copper Creek belt, the formation thins toward the southwest as the underlying Benbolt and overlying Wardell thicken. The calcilutite appears to show transitional relations with the upper Benbolt coarse limestone, and commonly acquires reddish tinges, as does the upper Benbolt in many places in Tennessee.

At Stickleyville, Virginia, the Gratton is fairly well developed, showing a few feet of the laminated zone 14 which is ordinarily absent southwest and west of Tazewell County. The Gratton is thin to absent at Glass Store, Virginia, where *Stromatocerium rugosum* appears directly above the cross-bedded zone 13. The Gratton apparently shows the southwest thinning observed in the median belts.

The Powell Valley belt shows the maximum development of the Gratton limestone. Between Tazewell and Sharps Chapel, Tennessee, the Gratton rests directly on the Beekmantown dolomites and in some places has a thickness of several hundred feet.

The Gratton was not recognized in the Cumberland belt, where younger beds overlie the Beekmantown and the lower Cliffield.

Correlation.—The beds comprising the Gratton have often been assigned to the "Lowville" in Virginia and Tennessee on the basis of the lithology and the presence of *Tetradium cellulosum* (Hall) and *Cryptophragmus antiquatus* Raymond. The younger Witten limestone also carries these forms and the true position of the type Lowville in the Virginia and Tennessee sequence is conjectural.

The Gratton has the same stratigraphic position, calcilutitic lithology, and to some extent fauna as the Snyder member[46] of the Benner formation in central Pennsylvania. *Cryptophragmus antiquatus* is found sparingly and *Tetradium cellulosum* found commonly in both.

WARDELL LIMESTONE

General character and fauna.—The Wardell formation has conformable relations with the overlying Bowen and underlying Gratton formations. The formation was named for the community of Wardell, Virginia, which is near the Russell-Tazewell county line, on U. S. Route 19. The type section[47] was taken from exposures 150 feet east of County Road 610 about 1 mile north of the ford across Little River and about 3½ miles northeast of Wardell. The formation consists of two lithologic and two faunal zones. Near the base a very persistent zone of *Stromotocerium rugosum* ordinarily occurs in gray, coarse-grained, commonly pink and cross-bedded limestone. *Stromatocerium* is in most places associated with *Columnaria halli* Nicholson, *Lichenaria carterensis* (Safford), *Solenopora compacta* (Billings), numerous *Girvanella*, and commonly *Dystactospongia*. Other fossils found in these beds in Tazewell County include *Pachydictya robusta* Ulrich, *Cheirocrinus angulatus*? Wood, *Carabocrinus* sp., *Diabolocrinus*, and *Batostoma* cf. *B.*

[46] G. M. Kay, *op. cit.*, p. 15.

[47] B. N. Cooper and C. E. Prouty, *op. cit.*, p. 873.

sevieri Bassler. The zone averages close to 50 feet thick in the type region.

Overlying the *Stromatocerium* beds are nodular limestone beds, zone 17, containing abundant *Receptaculites biconstrictus* Ulrich and other fossils.[48] The limestone is gray, fine-grained, argillaceous, weathering nodular and buff. The loose nodules commonly form loose rubbles which cover the outcrop. Southwest of Tazewell, Virginia, the beds become more shaly and thicken. In places a few coarse limestone lenses may be noticed.

Gray to pink calcarenite, zone 18, overlies the *Receptaculites* zone. The zone closely resembles the "Holston" marble of Tennessee. The beds are moderately fossiliferous but, as in zones 6, 10, and 13, the fossils are ordinarily too broken to be identified. Crinoid and cystoid fragments are very common.

The uppermost zone of the Wardell, zone 19, consists of light bluish gray, calcareous platy shales which become buffish on weathering. This zone contains an abundant bryozoan fauna with species belonging mainly to the genera *Chasmatopora*, *Eridotrypa*, *Escharopora*, *Graptodictya*, *Monotrypa*, and *Scenelopora*.

Distribution.—The Wardell formation is present, at least locally, in all the belts between Clinch Mountain and the Cumberland Front, showing maximum development in the median belts. The Wardell, in much the same manner as the Benbolt limestone, shows a general thickening and increase in argillaceous content southwest of Tazewell County, Virginia, to at least the Knoxville, Tennessee area.

In the Saltville belt, southeast of Clinch Mountain, the Wardell is generally absent.

Northeast of Clinch Mountain the Wardell occurs throughout the entire Copper Creek belt from Pearisburg, Virginia, where it is only about 10 feet thick, to the Knoxville region, where the beds are several hundred feet thick. In Tazewell County, Virginia, the upper calcarenite occurs only in the west part, with zones 16, 17, and 19 thinning to only a few feet and locally absent east of the town of Tazewell. In Thompson Valley the entire Wardell is about 100 feet thick; near Hansonville, Virginia, it is between 400 and 500 feet thick; and at Thorn Hill, Tennessee, it is close to 700 feet thick. *Stromatocerium rugosum* is well developed from Tazewell County, Virginia, southwest to at least Speers Ferry, Virginia, Southwest of this area the form appears only in a few places in the lower Wardell but the *Stromatocerium* of the underlying Gratton calcilutite is commonly found, as in the sections at Eidson and Thorn Hill, Tennessee. The fauna of the *Receptaculites* beds is well developed from Tazewell County, Virginia, to southwest of Speers Ferry, Virginia, but diminishes on passing into Tennessee. In the Knoxville area the calcareous shales of the upper Wardell are thicker and appear there to form the major portion of the Sevier formation. The shales of this zone contain mostly bryozoans and crinoids fragments as in Virginia, with the prolific fauna of zones 16 and 17 greatly diminished.

The coarse-grained zone 18 attains a maximum development in the Thorn Hill, Tennessee, section where it is 440 feet. Inasmuch as the thickness of the zone here is many times that recorded elsewhere, it appears that the thickening is local. Repetition by faulting may have occurred though the evidence for such was not observed. The Wardell here includes part of the "Holston" and "Ottosee" of Hall and Amick[49] in their detailed section. The base of the Wardell rests on the Gratton calcilutite with the actual contact in a covered zone (Hall and Amick's unit 744). The *Receptaculites* beds, zone 17, here include their units 744 to 754, a thickness of close to 200 feet. The coarse beds, zone 18, include their zones 754 through 774, the top of their Holston. The buff shale, zone 19, is somewhat nodular at the base, becoming more shaly toward the top. The zone contains Hall and Amick's units 775 to 782. A three-foot sandstone bed of the lower Bowen formation, zone 20, delimits the Wardell at the top.

The Wardell thickens from Thorn Hill southwestward to Knoxville (Fig. 4). Zones 16, 17, and 19 tend to lose their distinctive character and the Wardell and Benbolt combined become a thick series of interbedded calcareous shales and nodular limestones which can be lithologically differ-

[48] B. N. Cooper and C. E. Prouty, *op. cit.*, p. 839.

[49] George M. Hall and H. C. Amick, "The Section on the West Side of Clinch Mountain, Tennessee," *Jour. Tennessee Acad. Sci.*, Vol. IX, No. 2 (1934), pp. 214–17.

entiated in only a general way (Table VI). The term Sevier formation or shale is applicable in such cases.

In the St. Paul belt, the Wardell continues with only one interruption from Narrows, Virginia, through the type area near Wardell, Virginia, to and beyond Heiskell, Tennessee. As in the Copper Creek belt, the Wardell tends to wedge out northeast of Tazewell, Virginia. Near Springville, between

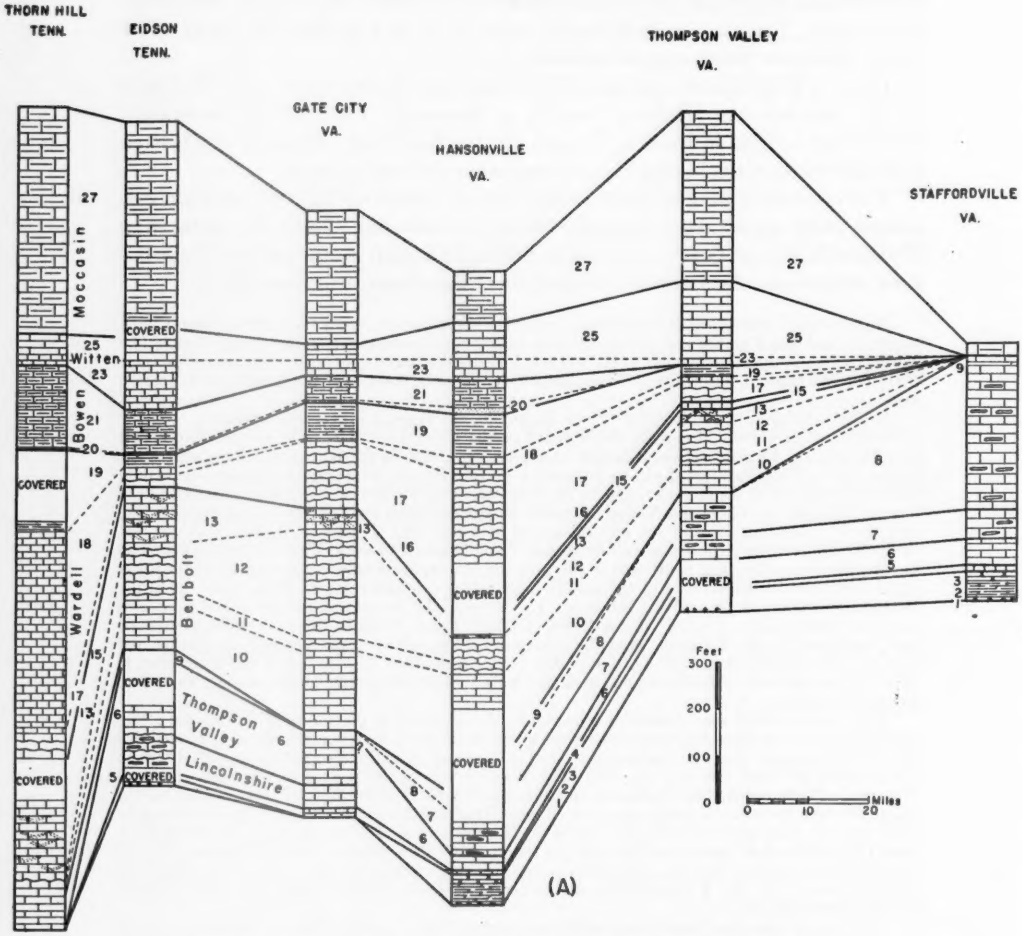

FIG. 4A.—Columnar sections of lower middle Ordovician in Copper Creek belt.

Tazewell and Bluefield, Virginia, it disappears entirely but reappears again in the section 2 miles north of Narrows, Virginia, where the Wardell, though only about 45 feet thick, shows a development of all its units, with zone 17 only partly represented (Table IX).

The Wardell is well exposed along U. S. Route 19, near the Russell-Tazewell County line. Butts[50]

[50] Charles Butts, "Variations in Appalachian Stratigraphy," *Washington Acad. Sci. Jour.*, Vol. 18, No. 13 (1928), pp. 369–70.

referred the nodular *Receptaculites biconstrictus* beds here to the "Ottosee" and used this section to illustrate a typical occurrence of that formation. In the section at Dickensonville, Virginia, southwest of this area, *Stromatocerium rugosum* appears to occur more infrequently, though the *Stromatocerium* of the underlying Gratton is well developed. The upper three units 17, 18, and 19 can be differentiated to at least the Evans Ferry section south of Tazewell, Tennessee. From here southwest the Wardell passes within a rather short distance into more typically Sevier lithology.

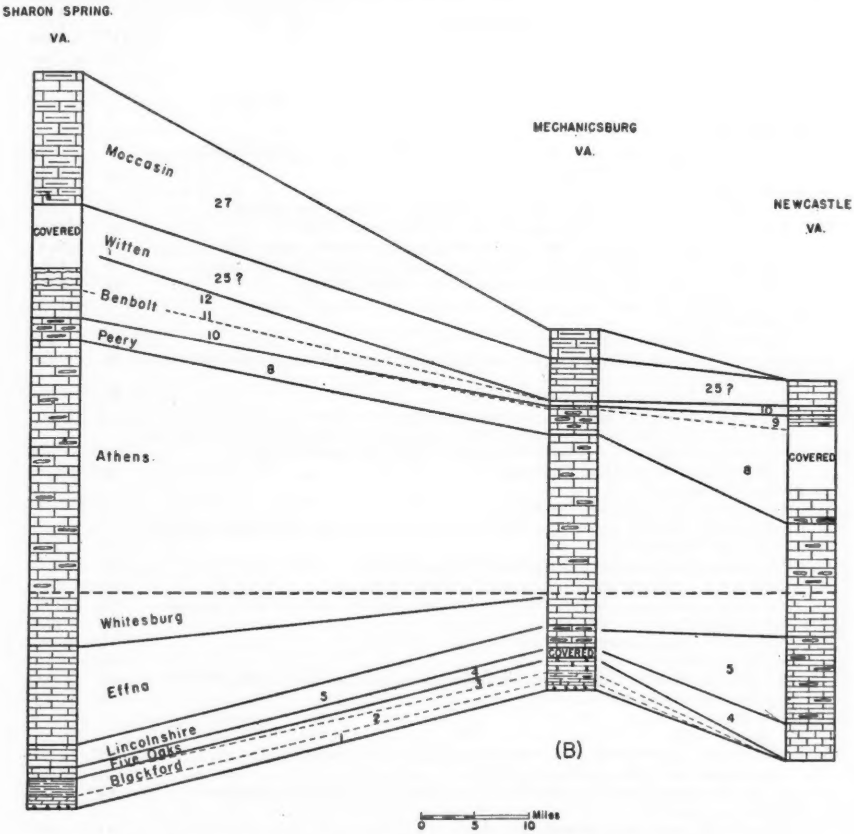

FIG. 4B.—Columnar sections of lower middle Ordovician in Saltville belt.

The Wardell shows good development in the Wallen Valley belt from northeast of Stickleyville to at least Tazewell, Tennessee. It is equally well developed throughout the Powell Valley belt except at the northeast end near Woodway, Virginia, where the Bowen formation directly overlies the Gratton. The formation is generally absent in the extreme northwest (Cumberland) belt. At Gully's Store, 2 miles west of Arthur, Tennessee, about 35–45 feet of buff, shaly limestone, which probably represents zone 19 of the Wardell, separates the Bowen sandstone above from the lower Cliffield below.

Correlation.—The Wardell formation of southwest Virginia has the same stratigraphic position and to a large extent similar faunal assemblage as the upper

TABLE IX

SECTION THROUGH LOWER MIDDLE ORDOVICIAN, 2 MILES NORTH OF NARROWS, VIRGINIA, ALONG VIRGINIAN RAILROAD

Description	*Thickness in Feet* *Of Unit*	*Thickness in Feet* *To Bottom of Formation*
Eggleston		
Moccasin formation		
Claystone, gray-green, maroon and buff intermixed; gray, argillaceous limestone occurring with pinkish marble at base	557	557
Witten limestone		
Limestone, fine-grained, gray-blue, thin-bedded, with few *Camarocladia*	18	176
Limestone, dark, fairly fine-grained, containing *Camarocladia*	16	158
Limestone, gray, coarse-grained, containing *Cryptophragmus antiquatus*	4	142
Limestone, thin-bedded; few beds having angular fragments (breccia zone)	8	138
Limestone, gray, and buff, laminated, medium- to fine-grained	13	130
Covered interval	117	117
Bowen formation		
Claystone, maroon, calcareous	10	41
Limestone, bluish gray, sandy, fine- to medium-grained; thin wavy laminations	31	31
Wardell formation		
Limestone, buff, shaly, gray when fresh	16	66
Limestone, gray, medium- to coarsely crystalline	4	50
Limestone, fine- to medium-grained, dark gray; containing abundant large *Girvanella* throughout interval and *Stromatocerium rugosum* near base	25	46
Covered interval (Gratton limestone?)	16	21
Benbolt limestone		
Limestone, gray, coarsely crystalline	5	5
Limestone, coarsely crystalline, slightly nodular in places, containing "*Chasmatopora*," *Girvanella*	28	224
Limestone, argillaceous, thin-bedded, slightly nodular	19	216
Limestone, dark gray, medium-grained, with bedded chert	19	197
Limestone, blue-gray, fine- to medium-grained, slightly cherty in lower portion	65	178
Covered interval	44	113
Limestone, bluish gray, fairly coarse	16	69
Covered interval	19	53
Limestone, dark gray, fine- to medium-grained, cherty, containing few *Öpikina*	19	34
Limestone, coarse-grained, gray	15	15
Cliffield group		
Perry limestone		
Calcilutite, light to dark gray, containing *Tetradium syringoporoides*	5	52
Limestone, light gray, medium-grained	2	47
Limestone, fine- to medium-grained, dark, cherty, containing *Lophospira*	45	45
Ward Cove limestone		
Limestone, very fine-grained, dark, dense	27	61
Covered interval	22	34
Limestone, gray, fine- to medium-grained, cherty	3	12
Limestone, very fine-grained	9	9
Lincolnshire limestone		
Limestone, fine-grained containing *Strophomena*	16	52
Covered interval	18	36
Limestone, dense, fine-grained, dark gray to black, cherty; containing *Sowerbyella* and *Leperditia*	18	18
Five Oaks limestone		
Limestone, fine-grained, semi-calcitutitic	9	9
Blackford formation		
Limestone, dark gray to black, with whitish-weathering, blocky chert	28	103
Limestone, ash-gray, shaly	55	75
Claystone, dolomitic, including chert and dolomite breccia at base	20	20
Beekmantown dolomite		

portion of the typical Sevier and "Ottosee" formations. The formation is apparently largely equivalent to the post-Benbolt portion of Ulrich's "Heiskell" shale, as probably referred by him to the Speers Ferry, Virginia, section. Due to inadequate description of the latter formation in the type area, presumably at Heiskell, Tennessee, the boundaries can only be inferred.

BOWEN FORMATION

General character.—The Bowen formation[51] takes its name from Bowen Cove, in the southwest corner of Tazewell County, Virginia. The type section, however, was taken from exposures along State Highway 91, ½ mile south of the intersection with County Road 604. The Bowen formation is composed of two units. The lower is a bluish gray calcareous sandstone, which weathers a rusty brown color. Most of the beds are irregularly stratified and commonly cross-bedded. The laminations generally consist of more resistant material which etch into relief on weathering, giving a characteristic appearance to the rock by which it may be easily identified. The upper unit consists of red calcareous claystone containing some greenish argillaceous limestone and is for the most part similar to the Moccasin formation, in which it has been generally included. Butts[52] considered the sandstone of zone 20 to be the base of the Lowville-Moccasin. A return to the original definition of the Moccasin necessitated the exclusion of the beds herein assigned to the Bowen formation and Witten limestone. The Bowen formation is unfossiliferous except for the presence here and there of *Tetradium fibratum* Safford. The Bowen is apparently conformable with the overlying Witten limestone and the underlying Wardell.

Distribution.—The Bowen formation is present, at least locally, in all the middle Ordovician belts between Clinch Mountain and the Cumberland Plateau, with the possible exception of the Wallen Valley belt. Southeast of Clinch Mountain the Bowen appears to be entirely absent from the Saltville belt. The formation has its best development (among belts autochthonous to the Saltville thrust) in the Copper Creek and St. Paul belts. In the former, the claystone phase, zone 21, is close to 60 feet thick just west of the town of Tazewell, Virginia, with the standstone zone absent. Northeast of Tazewell both zones appear to be absent to the end of the belt. The formation is locally present in Thompson Valley but absent from Burkes Garden. In the St. Paul belt the formation disappears northeast of Tazewell, Virginia, but reappears at least locally near Narrows, Virginia.

Southwest from Tazewell County, Virginia, the Bowen may be traced in both the Copper Creek and St. Paul belts well into Tennessee. The thickness of the sandstone is ordinarily less than 15 feet in Virginia but thickens gradually into Tennessee. The mudrock phase varies from about 40 to 100 feet in thickness, locally attaining a thickness of about 175 feet at Thorn Hill, Tennessee. The Bowen may be traced into Tennessee to at least Heiskell, where both the sandstone and claystone phase may be seen between the underlying Wardell and the overlying Witten limestone near the Heiskell Methodist Church. The claystone in this area assumes a buff color, rather than the ordinary maroon. This is commonly the case in Tennessee, not only of the Bowen claystone but of the Moccasin claystone.

In the Knoxville belt, allochthonous to the Saltville thrust, the Bowen was observed at several places between Knoxville and Lenoir City, Tennessee. Though poor exposures did not permit accurate measurements, the Bowen is apparently much thicker than in the autochthonous belts, attaining possibly 200 feet in places. The sandstone occurs at the top of the Sevier and is separated from the maroon Moccasin claystone by a few feet of limestone probably of Witten age. Southeast of the Knoxville belt the Bowen thickens markedly toward the source area on the southeast.

The Bowen appears to be generally absent from Rye Cove and the Wallen Valley belt. In the latter, however, the claystone zone was found to be locally present, as along the county road, 6 miles east of Tazewell, Tennessee.

[51] B. N. Cooper and C. E. Prouty, *op. cit.*, p. 876.

[52] Charles Butts, "Geology of the Appalachian Valley in Virginia," *Virginia Geol. Sur. Bull. 52* (1940), p. 182.

In the Powell Valley belt the claystone occurs from Woodway, Virginia, to at least Sharps Chapel, Tennessee, but the sandstone phase was not observed. In the Cumberland belt the Bowen is generally absent from Ben Hur, Virginia, to La Follette, Tennessee. In the section at Gully's Store, 2 miles west of Arthur, Tennessee, the Bowen is at least locally represented by about 2 feet of sandstone and about 30 feet of highly calcareous claystone.

Correlation.—The sandstone and claystone composing the Bowen formation have been generally included in the Lowville-Moccasin formation, largely due to the lithologic similarity of the Bowen and Moccasin maroon claystone. The Bowen, as indicated by Cooper[53] was not included in Campbell's original description of the Moccasin and thereby should not be considered as a part of that formation. The Bowen has no known equivalents outside of southwest Virginia and northeast Tennessee.

WITTEN LIMESTONE

General character and fauna.—The Witten limestone[54] was named for exposures along State Highway 16 about ½ mile north of County Road 604, just north of Thompson Valley at Scales, Tazewell County, Virginia. It is composed of pure limestone which is easily differentiated from the overlying and underlying maroon claystone. The formation may be divided in the fully developed section into two lithologic and two faunal units. The lower two units, zones 22 and 23, consist of laminated limestone and calcilutite similar to zones 14 and 15 of the Gratton limestone and might easily be mistaken for that formation. The laminated beds, zone 22, are ordinarily more argillaceous than the laminated beds of the Gratton. The zone is only slightly fossiliferous, containing mostly a *Tetradium* fauna consisting of *T. racemosum* Raymond, *T. fibratum* Safford, and *T. clarki*? Okulitch.

The calcilutite of zone 23 is somewhat more argillaceous than the older calcilutites, and in many places shows mud cracks and in some places beds of limestone breccia. The zone contains a fauna largely composed of *Tetradium*, including *T. cellulosum* (Hall), *T. fibratum*, Safford, and *T. clarki*? Okulitch. Other fossils include *Dystactospongia minor* Ulrich and Everett, *Helicotoma* cf. *H. verticalis* Ulrich, *Maclurites bigsbyi* (Hall), *Subulites regularis* Ulrich and Scofield, *Orthoceras multicameratum* Emmons, *Calyptaulax confluens* (Foerste,) and *Calliops callicephalus* (Hall). These beds average only about 25 feet in thickness in the type region.

The next zone above, the *Cryptophragmus* beds, consists ordinarily of about 10 to 25 feet of coarse-grained coquina limestone. The upper contact of the zone is gradational into the *Camarocladia* beds above and they commonly occur in thin layers within that zone. The most characteristic fossils besides *Cryptophragmus antiquatus* Raymond are *Zygospira recurvirostris* (Hall), *Hesperorthis tricernaria* (Conrad), and *Tetradium cellulosum* Hall. A number of other fossils have been identified from these beds.[55]

The *Camarocladia* beds, zone 25, form the top of the Witten limestone and

[53] B. N. Cooper, "Moccasin Formation in Southwest Virginia" (abstract), *Bull. Geol. Soc. America*, Vol. 53, No. 12 (1942), p. 1799.

[54] B. N. Cooper and C. E. Prouty, *op. cit.*, p. 877.

[55] B. N. Cooper and C. E. Prouty, *op. cit.*, p. 842.

consist of gray, even-bedded, fine-grained, limestone. *Camarocladia gracilis* Bassler is the most characteristic fossil, with *Buthotrepis inosculata* Bassler, common. The *Camarocladia* weather out and give a characteristic pitted appearance to the limestone. This zone is one of the most diagnostic in the lower middle Ordovician sequence and was used as the datum in the preparation of the columnar sections (Figs. 4 and 5). In Tazewell County the *Camarocladia* beds vary from about 45 to 75 feet thick. The zone underlies the Moccasin with apparent conformity.

Distribution.—The Witten limestone is represented in all the belts of middle Ordovician between Clinch Mountain and the Cumberland Plateau. The formation thickens to the northwest and shows maximum development in the Powell Valley and Cumberland belts (Figs. 5 and 7). The laminated limestone of zone 22 occurs infrequently throughout the belts in Virginia and Tennessee. The *Cryptophragmus* beds are not easily separated from the *Camarocladia* zone in most places and there is a tendency for the *Cryptophragmus*-bearing calcarenite to occur in distinct layers throughout the *Camarocladia* beds.

Southeast of Clinch Mountain the Witten is poorly developed. In the Saltville belt there are about 100 feet of unevenly textured, coarse to calcilutitic limestone. The lithology is different from the Witten northwest of Clinch Mountain but contains *Tetradium cellulosum* and a few specimens of *Camarocladia* and fucoids similar to the Witten, and the beds were questionably referred to the *Camarocladia* zone.

Northwest of Clinch Mountain the Witten limestone is persistent throughout the entire Copper Creek and St. Paul belts within the area of discussion. Near Shannondale. Virginia, 3 miles west of Bluefield, Virginia, on U. S. Route 19, the laminated zone of the basal Witten showed the maximum development observed for this zone, with about 80 feet represented. The Witten limestone of this area may be seen in the section in Table X.

TABLE X

SECTION THROUGH WITTEN AND MOCCASIN FORMATIONS AT SHANNONDALE, VIRGINIA, U. S. ROUTE 19, 3 MILES WEST OF BLUEFIELD, VIRGINIA

Description	*Thickness in Feet* — *Of Unit*	*Thickness in Feet* — *To Bottom of Formation*
Eggleston formation		
Moccasin formation		
Claystone, maroon, silty, slightly calcareous; containing a few thin beds of fine-grained, reddish brown sandstone (zone 27–28)	215	449
Claystone, maroon, silty, intercalated with light bluish gray, argillaceous, sparingly fossiliferous, limestone (zone 27)	156	234
Limestone, fine-grained to calcilutitic, red to gray with light green mottled beds, argillaceous; few *Camarocladia* near base (zone 26)	78	78
Witten limestone		
Limestone, dark bluish gray, fine-grained, with *Camarocladia gracilis*, *Tetradium cellulosum*, *T. racemosum*, and *Isocholina;* few intercalations of coarse-grained limestone similar to beds below (zone 25)	103	295
Limestone, thin-bedded, coarse-grained, slightly nodular, containing, *Cryptophragmus antiquatus*, *Zygospira* cf. *Z. recurvirostris*, *Escharopora* sp., and *Rhinidictya* sp. (zone 24)	10	192
Limestone, bluish gray, fine-grained to calcilutitic, somewhat laminated (zone 23)	61	182
Limestone, medium-grained, compact, thin-bedded with yellowish, argillaceous wavy streaks, and some black, nodular chert (zone 23)	43	121
Limestone, medium-gray, argillaceous, laminated, fine-grained to calcilutitic, with yellowish laminations which give fluted appearance to rock on weathering	78	78
Hiatus (Wardell and Bowen absent)		
Gratton limestone		

At Shannondale the Witten overlies the Gratton limestone in the absence of the Wardell and Bowen formations. Zone 23 in this section contains much argillaceous and coarse-grained material in addition to the calcilutite. The Witten continues with relatively little change in character or thickness well into Tennessee. In the section just north of Thorn Hill, Tennessee, along U. S. Route 25E, the *Camarocladia* zone reaches a thickness of 200 feet which is the maximum thickness observed for

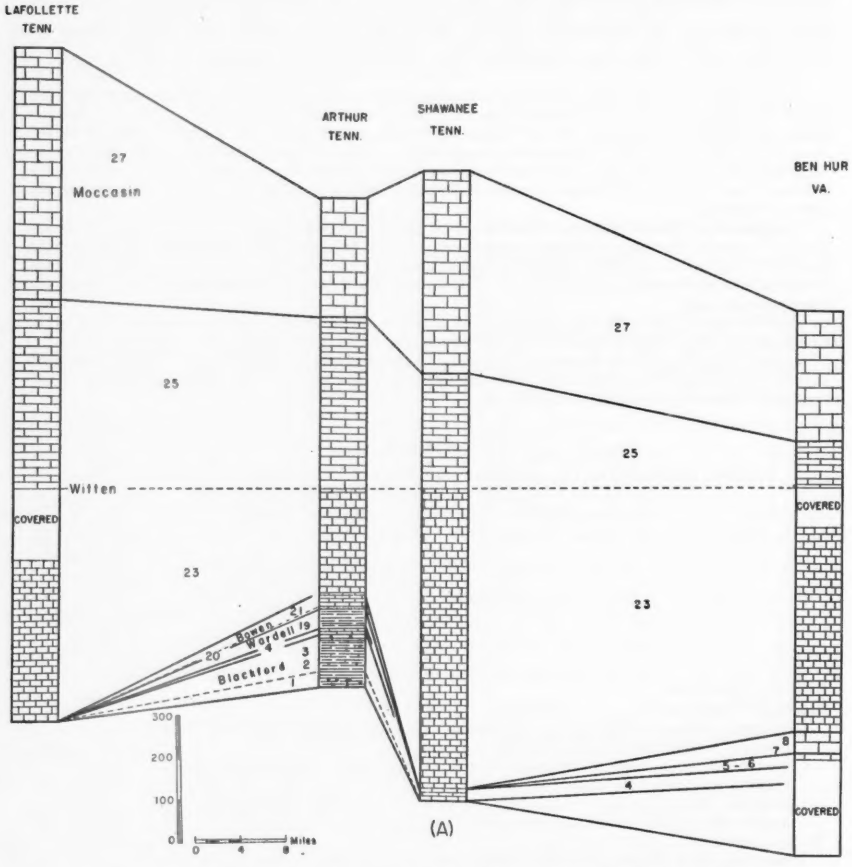

FIG. 5A.—Columnar sections of lower middle Ordovician in Cumberland belt.

this zone in the St. Paul belt. The *Cryptophragmus* beds in this section, as in many places in northeast Tennessee, do not form a distinct zone below the *Camarocladia* zone but occurs in distinct layers throughout the latter. It is interesting to note that the *Cryptophragmus*-bearing layers generally maintain the same coarsely crystalline, coquina-like lithology regardless of the horizon. At Heiskell, Tennessee, the same intermixing of the two zones occurs. In the section 5 miles west of Halls Crossroads, on the Knoxville-Norris road, all four units of the Witten are represented, including at least 25 feet of the basal laminated zone. The calcilutite beds, zone 23, are highly argillaceous here, showing many buffish-weathered beds.

Throughout Rye Cove and most of the Stickleyville belt, the Witten limestone is represented by less than 200 feet of the calcilutite and intermixed *Cryptophragmus* and *Camarocladia* beds. Northwest of this area in the Jonesville belt, however, the Witten thickens somewhat near Woodway, Virginia and Tazewell, Tennessee. Farther northwest, in the Cumberland belt, the calcilutite beds, zone

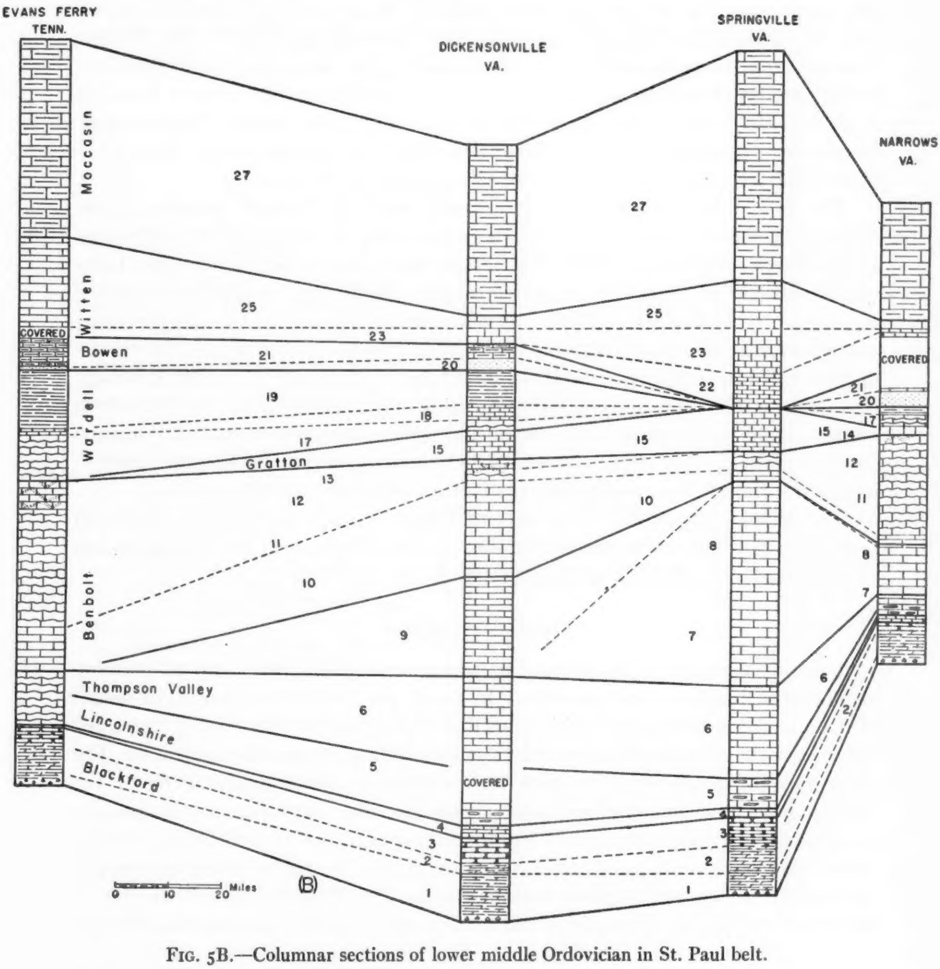

FIG. 5B.—Columnar sections of lower middle Ordovician in St. Paul belt.

23, increase from an average of less than 150 feet in the Powell Valley belt to more than 500 feet in the former belt, with the combined thickness of the *Cryptophragmus* and *Camarocladia* beds remaining fairly close to 300 feet in both belts, perhaps slightly thicker in the Cumberland belt. It is interesting to note that in the northwest belts the Witten limestone alone forms practically a third to half of the entire lower middle Ordovician sequence (Fig. 5).

Correlation.—The Witten limestone is equivalent to the beds generally called "Lowville" in this area. Ulrich correlated these beds with the Lowville of New York largely on the basis of *Cryptophragmus antiquatus* and *Tetradium cellulosum.* As will be indicated later there forms are now known to have longer ranges and this correlation can not be considered positive. Butts correlated the limestones with Moccasin formation and used the term "Lowville-Moccasin." The Witten however, appears to be older[56] than Campbell's type Moccasin near Gate City, Scott County, Virginia, where he referred to the limestones directly beneath (*Camarocladia* beds of the upper Witten) as the "blue, flaggy Chickamauga limestones." According to the original definition[57] of the Moccasin, these limestones (Witten) should not be considered a part of the Moccasin.

The Witten has several fossils in common with the Stover[58] member of the Benner limestone of central Pennsylvania including *Cryptophragmus antiquatus* and *Camarocladia.* Kay considers the Benner equivalent to the Pamelia and Lowville limestones of New York, in which case the Witten might likewise be partly equivalent to the Pamelia-Lowville. It is interesting to note that *Cryptophragmus antiquatus* also occurs sparingly in the Snyder member of the Benner limestone in Pennsylvania and in the Gratton limestone of Virginia, in similar lithology (calcilutite). The Witten and Stover forms occur abundantly in the two areas; are associated with *Camarocladia;* and occur generally in coarse-grained limestone (calcarenite). The similarity of these two *Cryptophragmus* zones suggests equivalency, and though not conclusive, it is further suggested by other fossils.

The Witten appears to have several forms common to both the Lebanon limestone and Tyrone formation in the Central Basin area of Tennessee but closer comparison should await further study.

MOCCASIN FORMATION

General character.—The Moccasin formation consists primarily of maroon, argillaceous limestone and claystone. In many places the basal portion consists of red and green variegated argillaceous limestone, zone 26, often called "marble" because of the occasional commercial use of the stone for interior decoration. The zone appears transitional between the underlying *Camarocladia* beds of the Witten limestone and the overlying claystone. The claystone phase, zone 27, comprises the greatest portion of the formation and consists mostly of maroon, often buff, olive, and gray, argillaceous limestone. In places there are several thin beds of wavy, red to green, metabentonite. The upper few feet of the Moccasin is in many places composed of red to olive siltstone or fine-grained sandstone,

[56] B. N. Cooper, *op. cit.*, p. 1799.
B. N. Cooper and C. E. Prouty, *op. cit.*, p. 879.

[57] M. R. Campbell, *U. S. Geol. Survey Estillville Folio 12* (1894), p. 2.

[58] G. M. Kay, "Middle Ordovician of Central Pennsylvania," *Jour. Geol.*, Vol. 52, (1944), pp. 17–19.

zone 28. The section along Plum Creek and State Highway 16, about 3 miles southwest of Tazewell, Virginia, illustrates the nature of the Moccasin and the relation to the underlying Witten limestone, and overlying Eggleston formation (Table XI).

TABLE XI

SECTION THROUGH WITTEN, MOCCASIN, EGGLESTON, AND LOWER MARTINSBURG FORMATIONS, STATE HIGHWAY 16, 3 MILES SOUTHWEST OF TAZEWELL, VIRGINIA

Description	Thickness in Feet: Of Unit	Thickness in Feet: To Bottom of Formation
Martinsburg formation		
Top of Claystone zone		
Metabentonite, buff, waxy	0.5	12.7
Siltstone, cuneiform-jointed, siliceous, bluish gray	0.6	12.2
Claystone, greenish gray, calcareous	2.3	11.6
Claystone, greenish gray, calcareous, contains numerous vugs and veins of secondary calcite	1.7	9.3
Metabentonite, buff	0.3	7.6
Claystone, cuneiform-jointed, silicified, dove-gray	3.0	7.3
Metabentonite, buff, waxy	0.2	4.3
Limestone, bluish gray, siliceous, cobbly, thin-bedded, ripple-marked; cuneiform-jointed brown chert bands at the top of zone containing *Dalmanella rogata* (Sardeson), *Rafinesquina alternata* (Emmons), and *Sowerbyella curdsvillensis* (Foerste)	4.1	4.1
Eggleston formation		
Shale, greenish gray, interbedded with lumpy calcareous siltstone	3.5	50.6
Shale, buff, bentonitic, with many seams of metabentonite 1½ inches or less thick (V7)	4.3	47.1
Limestone, partly silicified, cuneiform-jointed, bluish gray	7.0	42.8
Limestone, thin-bedded, dark gray and dark brown, argillaceous, cobbly; calcite vugs; a few ostracodes including *Eurychilina subradiata* Ulrich, *Leperditia sulcata* (Ulrich), and *Isochilina* sp.	12.1	35.8
Shale, greenish gray, bentonitic, with 1½ inches of red shale in middle	0.6	23.7
Claystone, greenish gray, calcareous, even-bedded, weathers nodular to cobbly; upper beds cuneiform-jointed	8.0	23.1
Limestone, cuneiform-jointed, siliceous, greenish gray, very fine-grained; contains greenish shale	5.1	15.1
Metabentonite, arkosic, blocky, mostly buff, with some maroon at base (V-4 of Rosencrans)	3.4	10.0
Limestone, cuneiform-jointed, greenish gray to dark gray, silicified in upper part; contains *Achatella transsectus* (Raymond) and a large species of *Isochilina*	2.1	6.6
Claystone, drab-gray, nodular, calcareous; contains many vugs of calcite; *Escharopora subrecta* (Ulrich) at top	4.5	4.5
Moccasin formation		
Claystone, gray, limy	4.5	386.0
Claystone, red and green mottled, more calcareous and finer-grained than below	20.0	381.5
Claystone, sandy, coarse-grained	1.0	361.5
Claystone, red and green mottled; greenish gray colors more pronounced than below. Two waxy, green, metabentonite beds, each 1 inch thick	10.0	360.5
Claystone, red with some 2–3-inch seams of greenish claystone	16.2	350.5
Metabentonite, green and red, waxy (V-2 Rosencrans)	0.3	334.3
Claystone, red with some thin seams of greenish mudrock	18.8	334.0
Shale, red, waxy; bentonitic	0.2	315.2
Claystone, massive, red	21.7	315.0

TABLE XI—(*continued*)

Description	Thickness in Feet	
	Of Unit	*To Bottom of Formation*
Shale, red, waxy	0.1	293.3
Claystone, massive, red	8.0	293.2
Shale, red, waxy, bentonitic	0.1	285.2
Claystone, red, with some greenish bands	28.0	285.1
Clay, green and red mixed, bentonitic, Gouge along small bedding thrust (V-1 Rosencrans)	1.0	257.1
Claystone, red, with thin intercalations of red and green mottled calcilutite	70.5	256.1
Calcilutite, greenish gray and maroon mottled, argillaceous	4.5	185.6
Claystone, calcareous and argillaceous limestone, red and green mottled	7.0	181.1
Calcilutite, dove-gray to greenish gray mottled, with thin intercalations of green and red waxy bentonitic shale	2.0	174.1
Claystone, bluish gray, calcareous, with few thin beds of limestone	1.8	172.1
Calcilutite, dove-gray, abundant calcite veins. Beds cut by jointing and faulting	4.5	170.3
Claystone, red, shaly, containing few greenish gray calcareous claystone seams	17.4	165.8
Calcilutite, light gray to greenish gray, with yellowish clay partings and few intercalations of pale reddish, marble	16.4	148.4
Claystone, red, silty, non-calcareous, mealy, with few greenish calcareous claystone seams	51.0	132.0
Claystone, red, with red and green mottled calcilutite	23.0	81.0
Limestone, maroon and greenish gray mottled, argillaceous	51.0	58.0
Marble, gray to green mottled, argillaceous, calcilutitic	7.0	7.0
Witten limestone		
Limestone, gray, calcilutitic, wavy bedding, with intercalations of coarse-grained limestone; abundant *Camarocladia gracilis*	12.0	89.3
Limestone, thin-bedded, medium-grained, interbedded with calcareous shale; few *Camarocladia*	4.0	77.3
Limestone, dark gray, calcilutitic, thin-bedded, containing lenses of coarse-grain limestones; number of *Camarocladia* and *Buthotrephis*	41.5	73.5
Limestone, coarse-grained, irregular-bedded, containing *Cyrtodonta* sp., *Leperditia fabulites*, and *Isochilina* sp.	19.8	31.8
Calcilutite, bluish gray, argillaceous, buff-weathering, bedding thin and irregular	12.0	12.0
Bowen formation		

It may be seen in Table XI that the Moccasin, though predominantly claystone, contains here and there thin beds of dove-gray to blue calcilutite. These intercalations have the general appearance of some of the Witten limestones but can be recognized through their thinness and general unfossiliferous nature. Most of the limestone beds, however, show mottled red and green colors and can be recognized on this basis alone.

The Moccasin is relatively unfossiliferous containing only a few specimens of *Camarocladia* cf. *C. gracilis* Bassler and *Tetradium fibratum* Safford.

Distribution.—The Moccasin formation is widespread throughout the various belts of southwest Virginia and northeast Tennessee. In the Saltville belt, however, the red claystone thins northeastward from about 300 feet near Sharon Spring, Virginia, to about 40 feet at Mechanicsburg, Virginia,

and disappears entirely before reaching the end of the belt just west of Newcastle, Virginia.

In the belts between Clinch Mountain and Cumberland Plateau, the Moccasin shows marked lithologic change both northwest across the belts as well as southwest along the belts into Tennessee. In the southeast belts of Virginia (Copper Creek and St. Paul) the Moccasin is developed similarly to the typical Moccasin near Gate City, Virginia, showing a preponderance of red claystone with a few beds of dove-gray to blue limestone intercalations and some red and green mottled beds. Southwest into Tennessee both belts show an increasing amount of buff argillaceous limestone and claystone replacing the red claystone. In the Copper Creek belt the change becomes noticeable near Eidson, Tennessee. At Thorn Hill, Tennessee, the buff claystone is more pronounced and near Halls Crossroads, north of Knoxville, Tennessee, the Moccasin appears to be predominantly buffish. In the St. Paul belt the section at Dickensonville, Virginia, shows probably half buffish claystone and southwest into Tennessee the proportion of buff to red increases until at Heiskell it is predominantly buff.

Northwest of the St. Paul belt, the claystone phase shows both red and buff colors in the Rye Cove area but changes in a short distance to predominantly buff in the Wallen Valley belt and continues thus in the Powell Valley and Cumberland belts. Other changes are noticeable in the Moccasin of the northwest belts. The buffish green claystone forms the lower half of the formation but the upper portion is more calcareous, consisting of light to dark gray, argillaceous, in many places laminated, limestone, containing considerable black chert and a few thin beds of greenish gray metabentonite. These beds may correspond with the zone of thin metabentonites found in the upper red claystone in the southeast belts, the thick metabentonites of the Eggleston lying above in both areas. In the latter area the Moccasin-Eggleston contact is readily drawn above the red claystone. In the northwest belts the upper Moccasin and lower Eggleston limestones are similar in appearance and a sharp contact is difficult to draw lithologically. The upper calcareous beds of the Moccasin are relatively unfossiliferous but commonly contain a few *Camarocladia* similar to those of the Witten. The lower shaly limestones of the Eggleston contain a fossiliferous zone with *Rhinidictya* and *Escharopora*.

Correlation.—The Moccasin formation as herein defined is equal to the upper portion of Butts' "Lowville-Moccasin" in the median and southeast belts. Butts included the red claystone of the Bowen within his Moccasin and the limestone intercalations he included in his "Lowville-Moccasin."

The Moccasin is equivalent to the "Bays" formation in its type area along Bays Mountain, southeast of Knoxville, Tennessee. It is equal to the Bays as mapped in the Knoxville folio[59] but not equivalent to the "Bays" of other folios in this area, where it was mapped for the younger Juniata formation. As the Bays has been often misused and is not as widely used as the Moccasin, it would best be discontinued. The Moccasin has been consistently classified as Black River in Virginia and Tennessee, but may be earliest Trenton.[60]

EGGLESTON FORMATION

General character and fauna.—The Eggleston[61] formation was defined to include the beds of upper Black River age which are younger than the upper red Moccasin and older than the Trenton. The type area along State Highway 8, one mile north of Narrows, Virginia, is composed of gray, thin- to thick-bedded, fine-grained, argillaceous limestone. There are also several beds of greenish gray metabentonite. In Tazewell County the Eggleston is somewhat similar, perhaps more argillaceous. The section in Table XI illustrates the Eggleston of this area.

[59] Arthur, Keith, *U. S. Geol. Survey Knoxville Folio 16* (1895), map.

[60] G. M. Kay, "Middle Ordovician in Western Anticlines in West Virginia and Central Virginia," *Bull. Geol. Soc. America*, Vol. 53 (1943), p. 1831.

[61] A. A. L. Mathews, "Marble Prospects in Giles County, Virginia," *Virginia Geol. Survey. Bull. 40* (1934), p. 11.

In the northwest belts the formation contains much grayish buff shale and claystone.

Besides the metabentonites, one of the most outstanding and persistent characteristics of the Eggleston lithology is the cuneiform jointing that occurs in the brittle, silicified beds commonly found in conjunction with the metabentonite beds.

The Eggleston is moderately fossiliferous. Some of the more common forms include *Escharopora subrecta* (Ulrich), *Rhinidictya nicholsoni* Ulrich, *Leperditella sulcata* (Ulrich), *Eurychilina subradiata* Ulrich, and a large species of *Islchilina.* These forms commonly occur in the lower part of the formation. The upper cuneiform beds contain such forms as *Dalmanella rogata* (Sardeson), *Sowerbeyella curdsvillensis* (Foerste), *Rafinesquina alternata* (Emmons), and other forms usually considered of Trenton age. In Table XI the contact of the Eggleston and the Trenton (or lower Martinsburg formation) was placed optionally below this fossiliferous zone. Several metabentonite beds or bentonitic shales may be found below the *Dalmanella* zone in the Eggleston and Moccasin. Four zones which are favorably comparable in position, thickness, and character with zones V-1, V-2, V-4, and V-7 of Rosencrans[62] were found in this section. The higher metabentonite beds in the lower Martinsburg of Table XI probably correspond with Rosencrans' beds V-8 through V-11. Beds V-4 and V-7 are the thickest and most easily recognized of the metabentonite zones. V-4 ordinarily ranges from about 1 to 4 feet in this area, is buffish and soapy in appearance, and can ordinarily be identified by its thickness alone. V-7 is commonly found from 30 to 45 feet above V-4 and in places approaches the thickness of that bed. Bed V-7 may be identified by a well formed cuneiform zone, in most places occurring directly above, which contains *Dalmanella rogata* and *Sowerbyella curdsvillensis.* The fauna above bed V-7, therefore, appears to be more closely associated with the overlying Trenton, and the Trenton (lower Martinsburg)—Eggleston contact was placed at this point. The V-7 metabentonite might be placed in the upper Eggleston or lower Trenton. The thickness of the interval between beds V-7 and V-4, however, is so persistent throughout the area, that there is little reason to assume a regional disconformity between the two beds. As characteristic Eggleston fossils occur between the beds, the contact should be at least above bentonite V-4. The most logical position for the contact then would appear to be above bed V-7 and below the *Dalmanella rogata* and *Sowerbyella curdsvillensis* zone.

Distribution.—The Eggleston is fairly well represented in all the belts of southwest Virginia and northeast Tennessee. The formation is not usually well exposed in most places, but commonly shows "scars" of greenish gray shale along the hillsides that are easily separated from the red Moccasin below. In the northwest belts, however, where the Moccasin mudrock has a gray to buff color, the two formations are not readily differentiated lithologically unless the thick metabentonite beds or the cuneiform beds are observed. The two thick metabentonites are recognizable throughout the entire area. Fox[63] and Grant mention two thick beds (B-3 and B-6) which are favorably comparable

[62] R. R. Rosencrans, "Stratigraphy of the Ordovician Bentonite Beds of Southwestern Virginia," *Virginia Geol. Survey Bull. 46-I* (1936), pp. 87–111.

[63] Portland P. Fox and Leland L. Grant, "Ordovician Bentonites in Tennessee and Adjacent States," *Jour. Geology*, Vol. 52, No. 5 (1944), pp. 322, 324, 326.

in thickness, position, and interval to V-4 and V-7 of the Eggleston. These beds were recognized by them in Alabama, Tennessee, and in parts of Virginia. The lower bed, B-3, is in most places underlain by chert and siliceous limestone, apparently silicified from the overlying metabentonite, and commonly showing cuneiform jointing. This bed is ordinarily better exposed than the less resistant calcareous claystone and calcareous shales above and below, and offers a good horizon marker. The zone was found in many sections of the southeast belts from Narrows, Virginia, to southwest of Eidson, Tennessee. In the northwest belts the zone was well exposed in the sections at Sharps Chapel, Jonesboro, west of Arthur, La Follette and Shawanee, Tennessee.

Though the Eggleston was observed in most of the sections studied, good exposures were rarely observed and the sections were generally ended at the lower chert and cuneiform bed below the B-3 bentonite bed.

Correlation.—Though no exact equivalents of the Eggleston are recognized, the formation appears at least partly equivalent to the Tyrone formation in the Central Basin of Tennessee on the basis of the two thick metabentonites (B-3 and B-6) and the included faunas, which show several bryozoans, gastropods, and ostracodes in common.[64]

The Eggleston has been correlated with a part of the lower Trenton Nealmont limestone of Pennsylvania on the basis of intertonguing of Nealmont and Eggleston facies in Highland County, Virginia, and the consistent presence of two metabentonites in the top of the lower (Oak Hall) member of the Nealmont and in the upper Eggleston.[65]

Summary and Recommendations for Reclassification

Although the revised classification in Tazewell County is somewhat local in nature, it can be usefully applied through much of southwest Virginia and northeast Tennessee. The use of the terms Murfreesboro, "Mosheim," "Holston," "Ottosee," "Heiskell," Lowville, and "Bays," should be discontinued as distinct formational names throughout this area. The typical Murfreesboro fauna of the Central Basin of Tennessee occurs chronologically above, rather than below, the "Mosheim," Lenoir, and "Holston." The Central Basin Murfreesboro has then been erroneously correlated into the Virginia and Tennessee sequence. Since the greater portion of the type Murfreesboro is unexposed, direct correlation cannot be successfully made into the Valley sequence.

Inasmuch as the "Mosheim" has been applied to a type of lithology occurring at different horizons within the Cliffield group, it is of no significance as a definite formational name and should be abandoned.

The Lenoir limestone was named by Safford and Killebrew[66] for the nodular, argillaceous, *Maclurites*-bearing limestone at Lenoir City, Tennessee. They considered it to be the same as the *Maclurea* limestone.[67] Since this was defined as occurring above the Knox dolomite (Beekmantown) and below the Marble

[64] George G. Huffman, "Middle Ordovician Limestone from Lee County, Virginia, to Central Kentucky," *Jour. Geol.*, Vol. 53, (1945), pp. 145-74.

[65] G. M. Kay, *op. cit.* (1944), p. 109.

[66] J. M. Safford and J. M. Killebrew, *The Elementary Geology of Tennessee* (Nashville, 1876), pp. 130-31.

[67] J. M. Safford, *Geology of Tennessee* (1869), pp. 232, 236.

("Holston" marble), it is likely that this is the definition intended at Lenoir City. This would here include the "Mosheim" (Five Oaks) limestone at the base. Since the naming of the "Mosheim"[68] in 1911, the Lenoir has been generally considered of post-"Mosheim," pre-"Holston" age. Though the upper Lenoir in the type section is covered, outcrops nearby show the typical Lenoir lithology to continue to the base of the "Holston." However, under a strict analysis of the original designation the boundaries are not sufficiently definite to preserve the validity of the name. In view of the wide use of the name it should best be retained, but should be redefined. In accordance with the common usage of the term, the Lenoir may be defined as the argillaceous, nodular limestones occurring between the "Mosheim" (Five Oaks limestone) and the "Holston" (Farragut limestone). Northwest of Clinch Mountain it would occur chronologically between the Five Oaks and the Thompson Valley limestone. The Five Oaks limestone is commonly absent in both areas and where the Blackford formation is absent the Lenoir rests directly on the Beekmantown.

The Lincolnshire limestone appears to be a more calcareous facies of the Lenoir. The Lenoir facies occurs mainly southeast of Clinch Mountain in Virginia and Tennessee. Though it occurs northwest of Clinch Mountain in Tennessee, it does not continue into Virginia.

The so-called "Holston" marble has no significance as a definite stratigraphic term and should not be used except in a commercial sense. The analysis of detailed sections indicated that the "Holston" has at various times been referred to at least four different coarsely crystalline horizons throughout Virginia and Tennessee. In place of the term "Holston" it is suggested that the particular crystalline bed be identified with zones 6, 10, 13, or 18, and the corresponding formation. The term Effna limestone is confined to the Saltville belt southeast of Clinch Mountain in Virginia. The term Farragut limestone is confined to the area southeast of Clinch Mountain or its extension (allochthonous to the Saltville thrust).

The Tellico formation of the Knoxville, Tennessee, area is not present northwest of Clinch Mountain in northeast Tennessee or in Virginia. In the Knoxville area it overlies the Farragut limestone and underlies the Sevier formation. As the Athens is probably equivalent in part to the Ward Cove limestone, and the lower Sevier equivalent to the Benbolt, the Tellcio would be pre-Benbolt, post-Ward Cove in age. The writer believes that if the Athens were present in the Knoxville belt it would occur between the Farragut limestone and the Tellico formation. The Athens occurs directly below the Tellico in the southeast belts. It is likely, then, that a hiatus exists between the Farragut and the Tellico in the Knoxville and South Knoxville (Vestal) belts.

The Sevier and "Ottosee" are essentially equivalent formations, the latter being named by Ulrich to obviate the use of the term Sevier, which had been

[68] E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. America*, Vol. 22 (1911), pp. 413, 414, 538, 543, 544, 557, and 636.

erroneously applied to the younger Martinsburg formation in much of the earlier mapping in Virginia and Tennessee. In this respect the Ottosee formation offers no improvement over the Sevier since it too has been applied erroneously in northeast Tennessee and southwest Virginia, especially the latter. The formation is further invalidated by the inadequate description of the type section in Chilhowee Park, Knoxville, Tennessee.

The Gratton limestone is generally absent in the Knoxville region and the Benbolt and Wardell equivalents are not readily differentiated lithologically, and due to a decreased faunal content in this area are not readily recognized faunally. The terms Benbolt and Wardell are then not applicable in this area and either Sevier should be redefined or a new formational name applied to these beds. The term Sevier is still commonly used in east Tennessee under the original definition by Keith[69] and should best be retained. According to the type description the Sevier occurs between the Tellico sandstone and the "Bays" sandstone. As correctly indicated by Butts[70] the type Bays is the same as the Moccasin. The latter is in better usage in Tennessee and Virginia and should have precedent over the "Bays." The base of the Moccasin as generally mapped was not included in the type Moccasin of Campbell, and was assigned the name Bowen.[71] The Bowen forms the base of the "Bays" and would therefore mark the top of the Sevier formation. The Sevier might be redefined as the bluish gray, buffish-weathering shaly limestones occurring between the Tellico sandstone and the Bowen formation. In the absence of the latter the Sevier would underly the Witten limestone and in the absence of this, would underly the Moccasin proper. The section southeast of Lenoir City, Tennessee, may serve as a standard for the Sevier (Table VI).

Inasmuch as the Sevier contains equivalents of the Benbolt, Gratton(?), and Wardell, it might be considered a group. However, it is useful as a mapping unit in Tennessee and is herein maintained under formational status.

The Chickamauga limestone of Chattanooga, Tennessee, has been completely subdivided into mappable units in the area under discussion and has little or no application therein.

Major Boundaries

The major boundaries of the lower middle Ordovician in Tennessee and Virginia are not as yet firmly established. Comparisons with the type sections of Chazy and Black River in New York have been largely unsatisfactory because of the great distance between the two areas and also because of the greater development of the section in Tennessee and Virginia in respect to both thickness and number of units.

[69] Arthur Keith, *op. cit.*, p. 4.

[70] Charles Butts, "Geology of the Appalachian Valley of Virginia," *Virginia Geol. Survey Bull. 52* (1940), p. 191.

[71] B. N. Cooper and C. E. Prouty, *op. cit.*, p. 876.

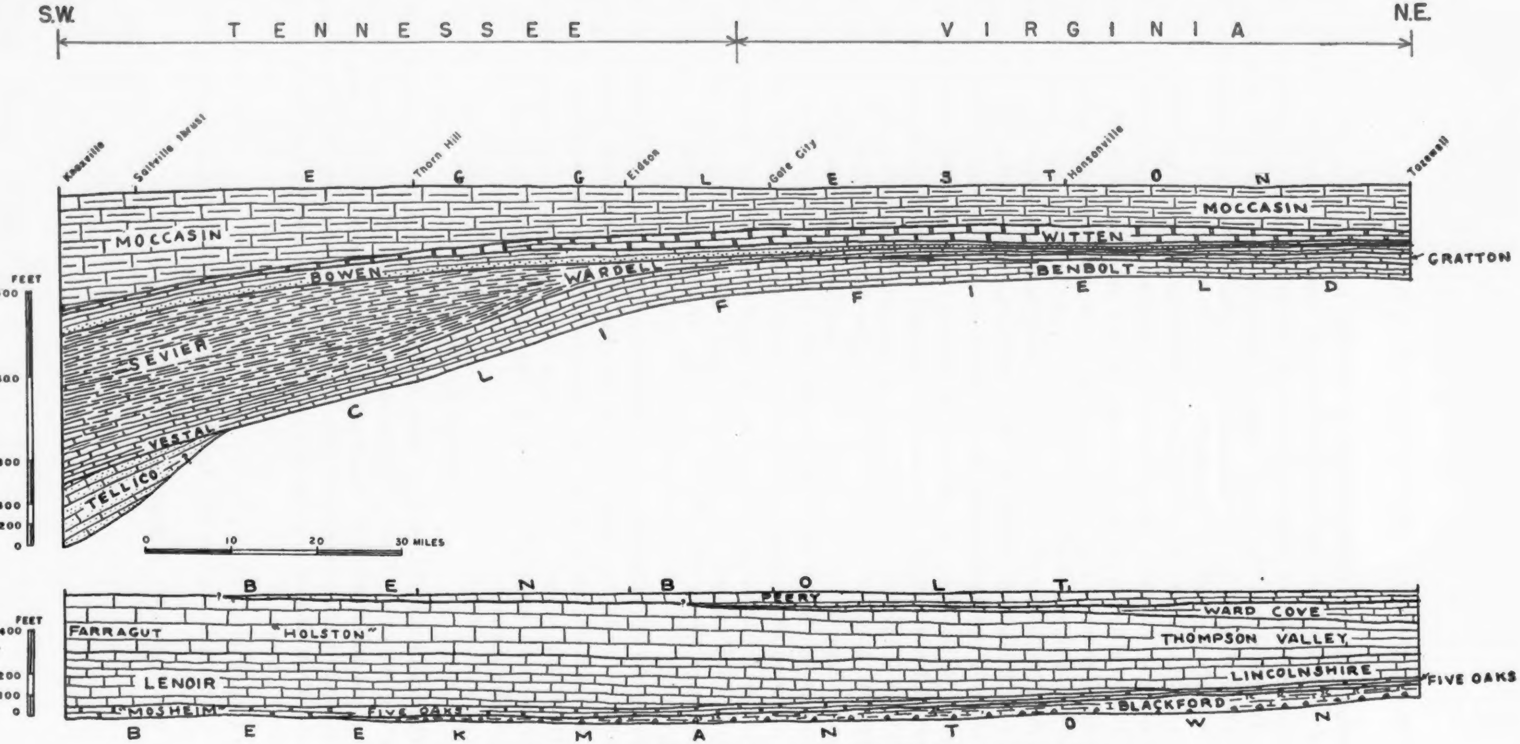

FIG. 6.—Restored section of lower middle Ordovician from southwest Virginia to northeast Tennessee.

The classification of Ulrich (Table I) has been generally followed throughout this area for a great many years, but must now be revised in the light of more recent studies. Ulrich placed the Stones River group in the base of Chazyan series. The basis for extending this group from the Central Basin of Tennessee was apparently his correlation of the Lenoir limestone with the Ridley limestone of the latter area, a correlation indicated earlier to be erroneous. There is, then, no valid basis for using this group in the Valley sequence. His Blount group comprised the upper Chazy and separated the Stones River from the Black River groups. He considered the thick sediments of this group, reaching a maximum of 3,500 feet in Grainger and Blount counties, Tennessee, to be absent from the New York section. There he placed the Pamelia limestone in the Chazy and considered it of upper Stones River age. He considered the Lowville lower Black River in age, and thought the Blount group to represent a hiatus between the Pamelia and Lowville.[72]

The Pamelia has been placed in the lower Black River group by Raymond,[73] Wilson,[74] Young,[75] and others. If Ulrich was correct in assuming the post-Pamelia age of the Blount group, the validity of the latter would obviously depend on the Chazy classification of the Pamelia. The disposition of the Blount group should be based on a more detailed comparison of the New York standard sections with the Virginia-Tennessee sequence.

The typical Lowville fossils, *Cryptophragmus antiquatus* and *Tetradium cellulosum*, are found also in the Pamelia. In Virginia they are found in both the Gratton and Witten limestones. It is not certain that these two zones correspond in the two areas. A few other fossils from the Witten are found in both the Pamelia and Lowville. The Gratton and Witten limestones are closely comparable with the Snyder and Stover members of the Benner formation of Pennsyluania which Kay[76] correlates with the Pamelia and Lowville of New York. The Black River-Chazy contact was placed beneath the Benner. Metabentonite beds aiding in the foregoing correlation are unfortunately absent in Virginia and Tennessee. By comparison with the foregoing areas, the base of the Gratton limestone appears to correspond fairly closely with the lower Black River contact. It would not necessarily follow that the pre-Gratton beds are pre-Pamelia Chazyan in age. The thicker developed section in Virginia and Tennessee could contain Black River older than Pamelia. Until this is conclusively demonstrated, however, the beds below the Gratton should be considered Chazyan.

[72] E. O. Ulrich, *op. cit.*, p. 557.

[73] P. E. Raymond, "The Trenton Group in Ontario and Quebec," *Geol. Survey Canada Summ. Rept. for 1912* (1914), p. 348.

[74] A. E. Wilson, "Notes on the Pamelia Member of the Black River Formation of the Ottawa Valley," *Amer. Jour. Sci.*, 5th Ser., Vol. 28 (1932), pp. 135–46.

[75] F. P. Young, Jr., "Black River Stratigraphy and Faunas," *Amer. Jour. Sci.*, Vol. 241 (1943), pp. 151–52.

[76] G. M. Kay, "Middle Ordovician of Central Pennsylvania," *Jour. Geol.*, Vol. 52 (1944), pp. 22–23.

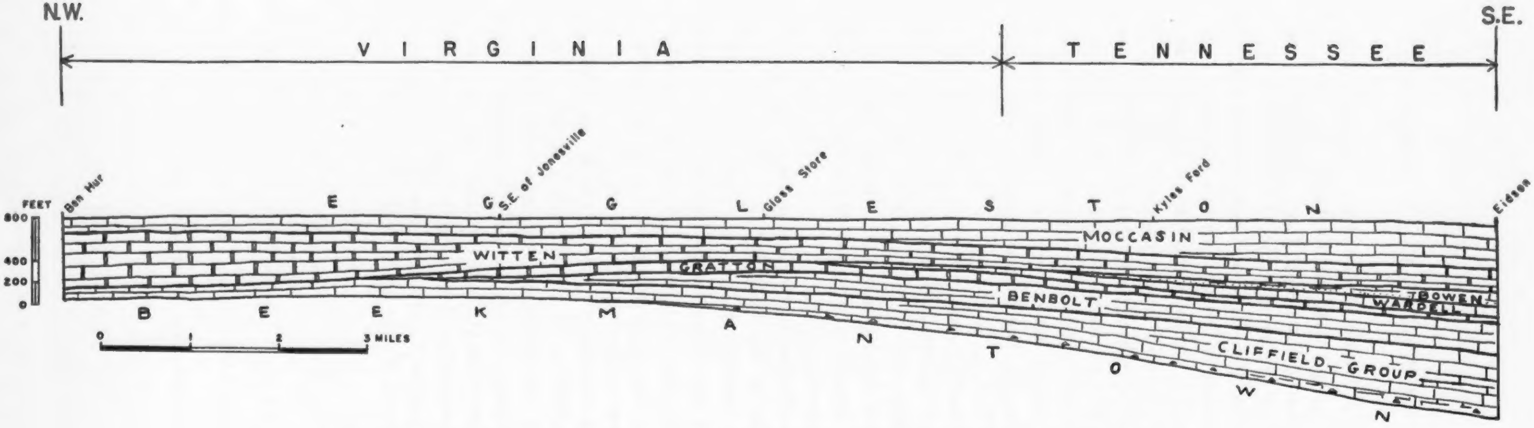

FIG. 7.—Restored section of lower middle Ordovician from northeast Tennessee to southwest Virginia.

The upper Black River contact is also conjectural, the main points having been discussed in the description of the Eggleston formation. The fossiliferous zone containing ***Dalmanella rogata*** (Sardeson), ***Sowerbyella curdsvillensis*** (Foerste), ***Rafinesquina alternata*** (Emmons), and other forms seems lower Trenton in age and the Witten clearly Black River. The Moccasin might be either late Black River or earliest Trenton.

Paleogeography

The discussion has concerned principally the sediments of the middle Ordovician exposed northwest of the Saltville thrust fault. The fault terminates northeastward in Virginia, and is considered the extension of the Adirondack axis of stratigraphic significance northward to New York and Quebec.[77] The area between the Saltville thrust and Adirondack line, and the axis of the Cincinnati arch has been called the Allegheny belt; that on the southeast the Champlain belt, forming the Appalachian allochthone margined by the Saltville thrust. The Allegheny belt formed the foreland of a geosynclinal Champlain belt for times during the middle Ordovician. The line of contrast has long been recognized as a "barrier" of some nature, referred to as the "Rome Barrier" by Ulrich and Schuchert[78] who postulated the presence of the "Lenoir Basin" on the southeast, the "Cumberland Basin" on the northwest. Butts[79] described the "Cahaba Barrier" in Alabama as lying along the Helena (Saltville) thrust. Ulrich[80] considered the "barriers" to be structural with linear lands responsible for many differences in section between the "troughs," a conclusion questioned by Raymond,[81] who thought there were changes in facies in continuous stratigraphic units. Van der Gracht attributed the contrasts across the Helena fault to the magnitude of the thrusting.[82]

The area northwest of the Saltville thrust-Adirondack line depressed unevenly during the early middle Ordovician, with gross tilting toward the southeast, the greatest and fullest section being in the Copper Creek and St. Paul belts nearest the Saltville thrust (Figs. 4 and 5). The thickness of sediments allochthonous to the Saltville thrust greatly exceeds that of autochthonous sediments. The rocks thicken gradually from the interior of the continent southeastward to the Saltville thrust, thence increase rapidly, particularly in Tennessee.

[77] G. M. Kay, "Development of the Allegheny Synclinorium and Adjoining Regions," *Bull. Geol. Soc. America*, Vol. 53 (1942), p. 1645.

[78] E. O. Ulrich and Charles Schuchert, "Paleozoic Seas and Barriers in Eastern North America," *New York State Mus. Bull.* 52 (1902), pp. 633–63.

[79] Charles Butts, "Description of the Bessemer and Vandiver Quadrangles," *U. S. Geol. Survey Folio 221* (1933).

[80] E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. America*, Vol. 22 (1911), pp. 450–52, 512–13; "Correlation by Displacement of the Strand Line," *ibid.*, Vol. 27 (1916), p. 454.

[81] P. E. Raymond, "Middle Ordovician of Virginia and Tennessee (abstract)," *ibid.*, Vol. 31 (1920), p. 137.

[82] W. A. J. M. van W. van der Gracht, "The Permo-Carboniferous Orogeny in South-Central United States," *K. Akad. Wetensch. Amsterdam, Afd. Naturk.*, 2nd Sec., Deel 27, No. 3 (1931), p. 111.

Towards the northwest, the interval between the top of the Eggleston and the Beekmantown averages from 1,300 to 1,600 feet in the Copper Creek and St. Paul belts, becoming 1,000 to 1,200 feet along the Powell Mountain anticline. Huffman[83] shows convergence from about 1,300 feet in Lee County, Virginia, to about 600 feet in Fayette County, Kentucky. Thicknesses from the top of the Tyrone (correlative of the Eggleston) to the top of the Beekmantown are shown in Figure 8, isopachs for Kentucky being from Freeman,[84] and for Tennessee

FIG. 8.—Isopach map showing interval between top of Tyrone (Eggleston) and top of Beekmantown dolomite (after Freeman, Born, and Wilson). Figures indicate continued southeast thickening of interval. Inset shows paleogeologic map on base of Trenton Cynthiana limestone (after McFarlan).

after Wilson and Born;[85] other figures were added from measured sections. The map shows general convergence from the Saltville thrust into Kentucky, and no apparent structure coinciding with the Cincinnati arch. Though convergence is toward the arch, the isopachs cross it irregularly, and thicknesses are less in

[83] G. G. Huffman, "Middle Ordovician Limestones from Lee County, Virginia, to Central Kentucky," *Jour. Geol.*, Vol. 53 (1945), pp. 147–74.

[84] L. B. Freeman, "Present Status of St. Peter Problem in Kentucky," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23 (1939), p. 1640.

[85] C. W. Wilson, Jr., and K. E. Born, "Structures of Central Tennessee," *ibid.*, Vol. 27 (1943), pp. 1045–1046.

Kentucky on the west than on the axis, and seem variably distributed in Tennessee. McFarlan[86] presented evidence (Fig. 8, inset) that the Cincinnati arch was not present in Trenton time in Kentucky.

Parallel with the strike of the belts autochthonous to the Saltville thrust, the rocks thicken from Virginia into Tennessee, especially in the post-Cliffield part of the section. The thickening is accompanied by an increase in clay content of the beds, a feature also characteristic of rocks allochthonous to the Saltville thrust.

In lower Cliffield time, basal clastics of the Blackford were deposited on the irregularities of the eroded Beekmantown surface. Dolomite and chert breccias with fragments to several inches in diameter indicate local relief. The succeeding fine-textured limestones, the Five Oaks, are present in both belts, suggesting relative stability throughout the region. In the Lincolnshire stage, the calcareous cherty beds principally northwest of the Saltville thrust become more argillaceous, nodular, and finer-textured in the Lenoir facies in the allochthone. The "barrier," perhaps a flexure with deepening of water and rapid sinking toward the southeast, was particularly effective in Virginia.

The contrasts become more striking, and the interpretation more evident in the upper Cliffield group. The Ward Cove limestone has similar stratigraphic position, and some of the fauna, of the much thicker Athens formation on the southeast in Virginia; in Tennessee the Ward Cove appears absent in the autochthone, in contrast to the even greater thickness and southeastwardly coarsening texture of the Athens in the allochthone (Fig. 9); the Athens graptolites are restricted so far as known to the allochthone. The "barrier" seems to have been a structural flexure, with greater sinking and deeper water on the southeast; the depression was at a maximum in eastern Tennessee where coarser detritus from the land farther southeast, Blountia, entered the geosyncline, and the seas did not cover the foreland on the northwest. The differences are not due to oscillation, with successive rather than contemporaneous deposition on the opposite sides of a hinge barrier.[87] The displacement along the Saltville thrust increases southwestward, with contrasts increasing on the two sides as greater areas of the zone of gradation along the flexure are concealed.

Beds similar faunally and lithologically to the Peery limestone directly overlie the Athens on the Saltville thrust slice southeast of Clinch Mountain in Virginia. Farther southeast in the Draper Mountain area south of Pulaski,[88] these, together with the *Nidulites* beds of the Athens (Ward Cove) were at one time

[86] A. C. McFarlan, "Stratigraphic Relationships of Lexington, Perryville, and Cynthiana (Trenton) Rocks of Central Kentucky," *Bull. Geol. Soc. America*, Vol. 49 (1938), pp. 989–96.

[87] E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. America*, Vol. 22 (1911), p. 292.

[88] B. N. Cooper, "Lower Paleozoic Unconformities near Draper, Virginia, and Their Significance," *Jour. Geol.*, Vol. 47 (1939), pp. 509–16; ———, "Geology of the Draper Mountain Area, Virginia," *Virginia Geol. Survey Bull. 55* (1939).

referred to the "Chambersburg," which until recently has been considered entirely post-Lowville. Thus, a great hiatus was thought to be present below the "Chambersburg" of southwest Virginia to explain the absence of the "Lowville"

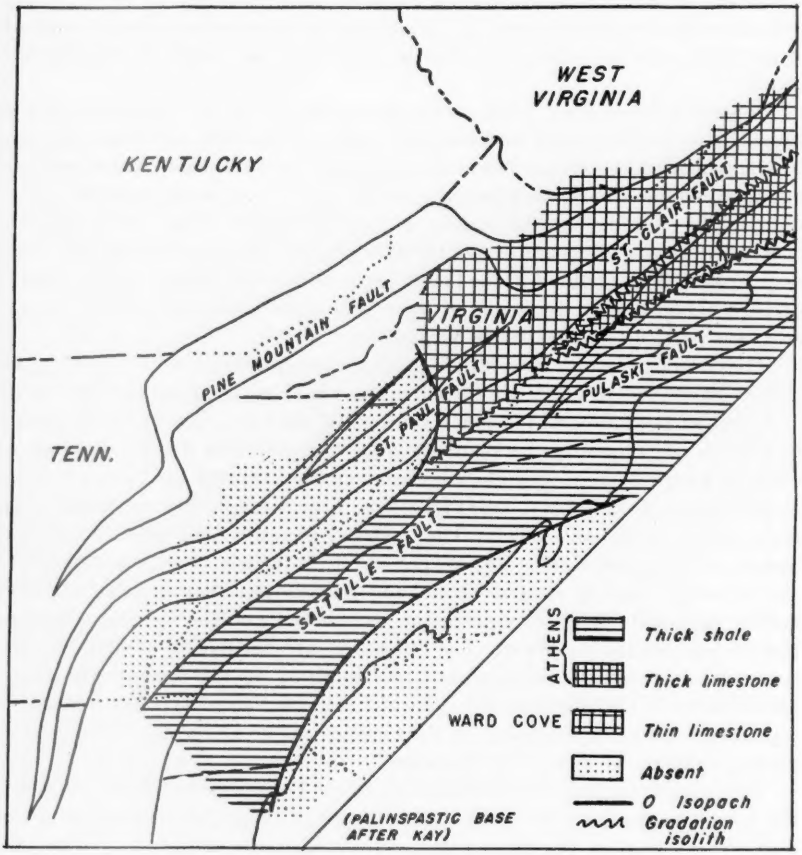

FIG. 9.—Map showing approximate distribution of Ward Cove and Athens facies in southwest Virginia and northeast Tennessee.

and Moccasin.[89] Inasmuch as the Athens-"Chambersburg" of this area seems largely equivalent to the Ward Cove and Peery, the hiatus is not required, though there is a succeeding unconformity since the overlying rocks are Moccasin and Eggleston.

[89] Charles Butts, "Geology of the Appalachian Valley in Virginia," *Virginia Geol. Survey Bull. 52* (1942), pp. 197–98.

In post-Cliffield time, the flexure or "barrier," influencing currents, separated the Benbolt, Wardell, and Bowen formations from the more clastic, thicker Sevier facies in the geosynclinal area on the southeast in Tennessee, evidently affected by the continued presence of Blountia on the southeast. A similar change to thicker, more clastic beds occurs from Virginia into Tennessee in the southeastern autochthonous rocks; contrast across the Saltville thrust is not great in Virginia.

The Moccasin formation shows maximum development and becomes more argillaceous and coarser[90] in the allochthonous sections, reflecting the southeastward source. Butts[91] lists a thickness of 830 feet southeast of Blacksburg, Virginia; it is about 1,200 feet a mile southeast of Lenoir City, Tennessee, on the south side of the Tennessee River. The formation thins southeast in the extreme southeastern belts in Virginia, being only about 150 feet near Marion and Crocketts Cove, and absent near Draper; its overlap on the Cliffield indicates pre-Moccasin upwarping of the southern part of the area of the Athens geosyncline. The same pre-Moccasin bevelling was observed northwest of the Saltville fault extension in Rich Patch, Warm Springs, Hightown, and Bolar valleys, and also by Kay[92] southeastward into the Shenandoah Valley. A similar regional unconformity has been reported in Pennsylvania.[93]

Northwest of the Saltville fault in Virginia, the Moccasin averages about 250 to 350 feet. The outstanding lithologic change is from the typical red claystone of the southeast and median belts to the greenish buff claystone and limestone in the northwest belts. The color isoliths do not conform to the structural belts, but cross at a small angle, tending to show the red to buff change from Virginia to Tennessee more rapidly along the northwest belts. The reasons for this change in coloration, and the position of the isoliths relative to structure, source direction, and shores require further investigation.

The stratigraphy of the succeeding Trenton, "Martinsburg formation," has been subdivided only locally[94] and has not been studied in detail. The rocks are dominantly argillaceous limestones in the area northwest of the Saltville thrust. The middle Trenton is thin and calcareous northwest of the Adirondack line from central Virginia to Quebec and seems to be thicker and predominantly of dark shale toward the southeast. This contrast is attributed to greater subsidence along a flexure comparable in position and character with that limiting the older Ward Cove and the Athens in southwest Virginia.

[90] Charles Butts and R. S. Edmundson, "Geology of the Southwestern End of Walker Mountain," *Bull. Geol. Soc. America*, Vol. 54 (1943), p. 1678.

[91] Charles Butts, *ibid.* (1942), p. 187.

[92] G. M. Kay, "Middle Ordovician Limestones in Western Anticlines in West Virginia and Central Virginia" (abstract), *Bull. Geol. Soc. America*, Vol. 53 (1942), p. 1831.

[93] L. C. Craig, "Middle Ordovician of the Chambersburg Region, Pennsylvania" (abstract), *Bull. Geol. Soc. America*, Vol. 52 (1941), p. 1963.
G. M. Kay, "Middle Ordovician of Central Pennsylvania," *Jour. Geol.*, Vol. 52 (1944), pp. 102–03.

[94] G. G. Huffman, "Middle Ordovician from Lee County, Virginia, to Central Kentucky," *Jour. Geol.*, Vol. 53 (1945), pp. 145–75.

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GRAIN ROUNDNESS—A VALUABLE GEOLOGIC TOOL[1]

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ABSTRACT

The roundness of heavy minerals can be a valuable tool in oil and gas exploration and other geologic work. In the Appalachian Basin roundness has been used to differentiate producing zones, outline petrographic provinces, and help to interpret geologic history. Examples are presented.

INTRODUCTION

The roundness (angularity) of sand grains is a property whose usefulness apparently has not been fully recognized by many geologists. Certainly the literature contains few examples of roundness being used to solve oil and gas problems. Notable is the work of Trowbridge and Mortimore[3] on the "Wilcox," Hominy, Bartlesville, and Elgin sands of Oklahoma. Recently Rittenhouse[4] and Sidwell[5] have used roundness of heavy minerals to differentiate sands of different age. Undoubtedly much unpublished information is in the files of some oil companies, but unfortunately such data are not generally available.

In the Appalachian Basin roundness of heavy minerals is exceedingly valuable as a criterion for differentiating various Mississippian and Pennsylvanian oil and gas sands, for outlining petrographic provinces, and for interpreting geologic history. Roundness is particularly significant in the Basin because fossils are rare and the heavy-mineral suite is restricted. It is hoped that the examples and discussion that follow will serve to reemphasize the value of roundness and to stimulate increased use of this geologic tool in the Appalachian Basin and elsewhere.

ROUNDNESS AND SPHERICITY

As pointed out by Wadell,[6] roundness and sphericity (shape) are independent properties of sediment particles. Roundness is a measure of the angularity of the corners of grains. In contrast, sphericity may be considered as a ratio between the length and breadth of a grain.[7] The difference between these two properties is illustrated by Figure 1. Grain A has high roundness and high sphericity. Grain B

[1] Manuscript received, January 10, 1946. Published by permission of the director of the Geological Survey, United States Department of the Interior.

[2] Geological Survey. The writer wishes to thank Miss Elaine Cather for her able assistance in the laboratory, and the University of West Virginia and the West Virginia Geological Survey for use of their office and laboratory space and equipment.

[3] A. C. Trowbridge and M. E. Mortimore, "Correlation of Oil Sands by Sedimentary Analysis," *Econ. Geol.*, Vol. 20 (1925), pp. 409–23.

[4] Gordon Rittenhouse, "Investigation of Oil and Gas Sands in the Appalachian Basin," *Producers Monthly*, Vol. 8 (1944), pp. 19–21.

[5] Raymond Sidwell, "Triassic Sediments in West Texas and Eastern New Mexico," *Jour. Sed. Petrology*, Vol. 15 (1945), pp. 50–54.

[6] Hakon Wadell, "Volume, Shape, and Roudness of Rock Particles," *Jour. Geol.*, Vol. 40 (1932), pp. 443–51.

[7] This gives only an approximation of values obtained by Wadell's methods. See footnote 6.

has high roundness but the sphericity is much lower—the length of the grain is much greater than its breadth. Grain C has very low roundness—the corners are very sharp—but it is nearly equidimensional and consequently has a fairly high sphericity.

To determine roundness, Wadell projected grains to a standard size, measured the radius of curvature (r) of the corners and the radius of the maximum inscribed circle (R). Roundness (P) was computed from the equation $P=\sum\frac{r/R}{N}$, in which N is the number of corners measured. Using this equation, roundness of grains ranges from 0 to 1.

Wadell's method is very time consuming and can not be used when a large number of samples must be examined rapidly. In the Appalachian Basin work,

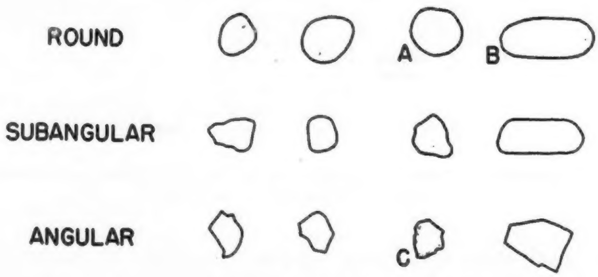

FIG. 1.—Representative round, subangular, and angular grains.

many problems were solved by using a less precise method that involved only three roundness classes, namely, round, subangular, and angular (Fig. 1). These are roughly equivalent to Wadell values of 1.0–0.6, 0.6–0.1, and 0.1–0.0, respectively. For rapid practical work, 0.1 is a more easily defined break between subangular and angular than a value of about 0.3 or 0.4.

For some problems, greater detail will be necessary. For this, a comparison chart similar to that devised by the writer[8] to measure sphericity must be developed. Krumbein[9] has published such a chart for estimating the roundness of pebbles, but it does not work well for sand grains.

PRACTICAL USES OF ROUNDNESS

Example I.—Differentation of producing zones.—In northern Ohio the Mississippian and lower Pennsylvanian sands are highly lenticular, some formations

[8] Gordon Rittenhouse, "A Visual Method of Estimating Two-dimensional Sphericity," *Jour. Sed. Petrology*, Vol. 13 (1943), pp. 79–81.

[9] W. C. Krumbein, "Measurement and Geological Significance of Shape and Roundness of Sedimentary Particles," *Jour. Sed. Petrology*, Vol. 11 (1941), pp. 64–72.

passing from sandstones several hundred feet thick to shales and siltstones in a distance of 10 miles or less. Further, the Mississippian formations have been truncated progressively from south to north and lenticular lower Pennsylvanian sands deposted in the valleys. These valleys may have a local relief of a hundred feet or more. Thus, several sands may occur at about the same level.

The main problem here is to separate the Black Hand (Big Injun) sandstone of Mississippian age from the Sharon (Maxton) and Massillon (Salt) sandstones

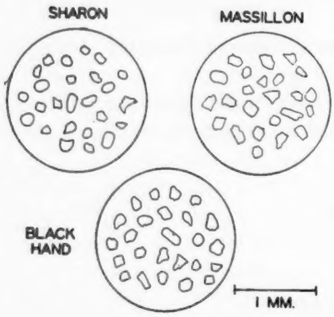

FIG. 2.—Representative tourmaline grains from the Massillon, Sharon, and Black Hand formations of Ohio ($\frac{1}{8}$–$\frac{1}{16}$ mm. size).

of lower Pennsylvanian age. Figure 2 shows the outlines of representative tourmaline grains from these three sands. Some differences are apparent from superficial examination. The Sharon has more round grains than the others; the Massillon has a much higher percentage of angular grains. The Black Hand is intermediate.

When quantitative counts are made on a number of samples of each formation and the results are plotted on a triangular diagram the picture, as shown by Figure 3, is much clearer. Each formation occupies its own part of the diagram, though there is a slight overlap of the Black Hand and Massillon. Thus, by determining the percentage of round, subangular, and angular tourmalines, an unknown from this general zone can be identified.[10] Actually there are other criteria that supplement roundness, namely, the percentage of chromite in the zircon-chromite-rutile ratio, and the ratio of pink zircons to other zircons.

Example II.—Outlining petrographic provinces.—Throughout much of Ohio, northwestern Pennsylvania, and southwestern New York, the basal Pottsville formation is a sandstone or conglomerate. In New York and much of Pennsylvania this is called Olean; in Ohio and adjacent Pennsylvania it is the Sharon.

[10] Cable-tool cuttings show little fracturing of the small ($\frac{1}{8}$–$\frac{1}{16}$ mm.) heavy-mineral grains, even in well cemented rocks. In contrast, breakage across quartz grains, together with secondary growths on them, so modifies their original shape that they cannot be used in much of the Appalachian Basin.

The unity of the Sharon and Olean as a continuous lithologic unit was established by Carll and Ashburner.[11] Where conglomeratic, the Sharon and Olean are similar in megascopic appearance, being characterized by round to subangular, ovoid quartz pebbles in a matrix of fine to coarse sand. From the continuity, megascopic appearance, and similarity of primary structures, it might easily be

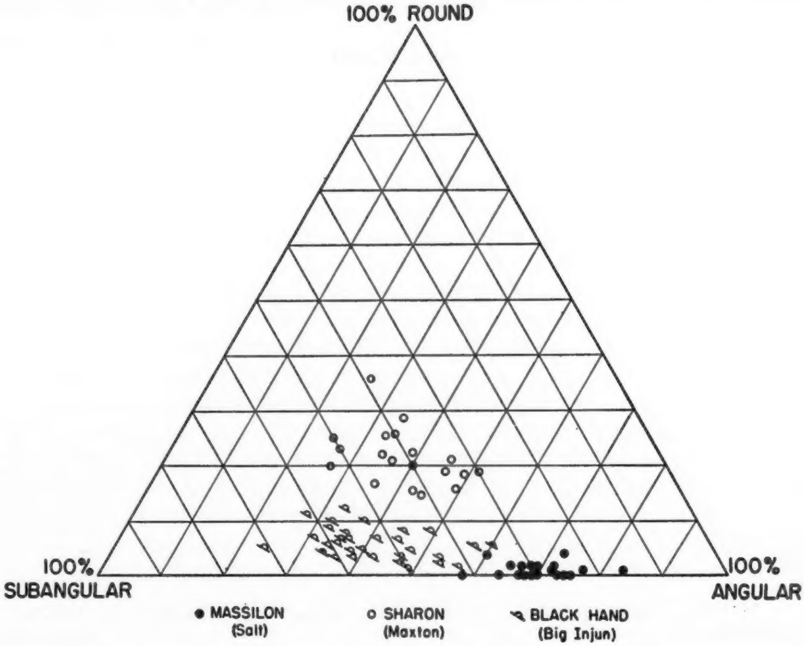

FIG. 3.—Roundness of tourmalines in Massillon, Sharon, and Black Hand formations of Ohio ($\frac{1}{8}$–$\frac{1}{16}$ mm. size).

assumed that the Olean and Sharon were derived from the same source and were deposited under the same conditions.

Although the conditions of accumulation of the Olean and Sharon may have been similar, the source, at least of the sand, was not. In reaching this conclusion, the difference in roundness of the heavy minerals provides one important line of evidence. In the Olean and the easternmost Sharon the tourmalines are more angular than in the Sharon to the west. This is clearly shown in Figure 4. Further, in the Olean euhedral zircons are common and round zircons are rare. In the

[11] C. A. Ashburner, "The Geology of McKean County," *Pennsylvania Geol. Survey Rept. Prog. R* (1880), pp. 61–62.

Sharon the reverse is true. The east to west change from Olean to Sharon type roundness appears to be sharp, not gradational as might be expected if the Sharon had been derived from the east and owed its higher roundness to greater distance of transport.

The difference in roundness is also associated with differences in mineralogical composition. In twenty Sharon samples the percentage of chromite in the zircon-chromite-rutile ratio averaged about 30 per cent; in nine Olean samples the

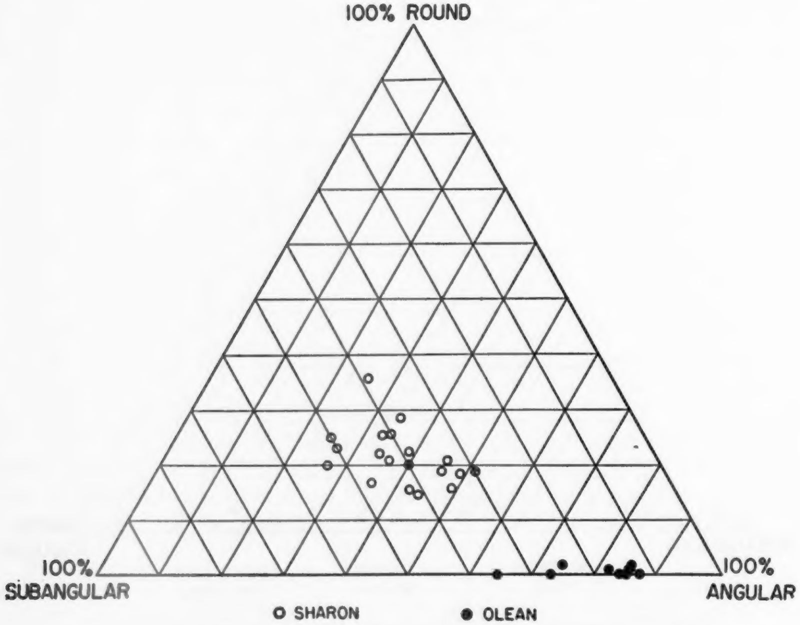

FIG. 4.—Roundness of tourmalines in the Sharon and Olean formations ($\frac{1}{8}$–$\frac{1}{16}$ mm. size).

average was about 2 per cent and the maximum value was about 6 per cent. The proportion of pink zircon to other zircon also differs in the Olean and Sharon.

The Sharon-Olean study establishes roundness as an independent criterion that may be used (with caution) to outline petrographic provinces within a lithologic unit. This criterion has been used effectively in subdividing other Appalachian Basin formations into petrographic provinces. Best example to date is the Berea sandstone, in which differences in mineralogical composition are slight. Full data on the Berea will be published in a subsequent paper.

Example III.—Interpretation of geologic history.—In northern West Virginia the Berea sandstone is absent from the greater part of several counties. Farther

south in West Virginia the Weir sand, which is also Pocono in age, occurs at a higher stratigraphic level than the Berea. Toward the north the Weir is a medium to coarse, locally conglomeratic sand. Southward it becomes finer and grades into siltstone. Pebbles of dark gray shale in the Weir suggest possible derivation from the Sunbury shale, a dark gray to black shale that overlies the Berea in some parts of Ohio and West Virginia. Some geologists have postulated that the Weir was derived, at least in part, from erosion of the Berea sandstone and Sunbury shale in that part of northern West Virginia from which they are now missing.

In the Berea sandstone immediately west of the absent area the tourmaline and zircon grains are exceedingly well rounded. On the average more than 50 per cent of the tourmalines are round and only a few per cent are angular. The Weir sand, however, is characterized by angular tourmalines—only a few per cent being round and more than half being angular. Many of the angular grains in the Weir are euhedral crystals or fragments of euhedral crystals, and only a small percentage have curved surfaces that would suggest derivation through fracturing of rounded or subangular grains. Although differences in mineralogical composition are so slight as to be inconclusive, the difference in roundness of heavy minerals provides conclusive evidence that the Weir could not have been derived in any large part from the Berea.

Elimination of this hypothesis strengthens the alternative interpretation that the Berea "absent" area of northern West Virginia was due to non-deposition, and that the Berea deposits on the west were shore or near-shore accumulations. This in turn provides information on the probable size, shape, and trend of Berea sand bodies and thus will help in the exploration for oil and gas.

A further implication from the difference in roundness is that an important, and perhaps major break of some type occurred in the Pocono between Berea and Weir time. Preliminary results of a study of the Pocono sands of western Pennsylvania indicates that a break also occurs in that area. In Pennsylvania, a similar though less pronounced difference in roundness is accompanied by a recognizable change in mineralogical composition.

The nature of the break within the Pocono is not entirely clear at the present time. Certainly a change in source material is indicated, but just how and why the source changed has not yet been determined.

SUMMARY AND CONCLUSIONS

Examples that show how roundness of sand grains can be used to differentiate producing zones, outline petrographic provinces, and interpret geologic history have been presented. Other examples could be given. Used intelligently and with due regard for its limitations, roundness can be a valuable tool in oil and gas exploration.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 7 (JULY, 1946), PP. 1198-1199

GEOLOGICAL NOTES

HALF-PAGE METHOD OF MANUSCRIPT PREPARATION[1]

W. ARMSTRONG PRICE[2]
Corpus Christi, Texas

There may be those who can compose a scientific paper in a single writing and turn it out with the proper unity, balance, and typography. This writer is seldom if ever in this class of whole-in-one authors.

To some, perhaps, the particular form of the manuscript is unimportant, provided it meets the editor's requirements in being neat, clean, and in the proper style for the intended publication. But for the many who write, revise, rearrange, and write again, there is a method of manuscript construction which sidesteps much of the agony and perplexing delay of the planless method and can greatly improve the product, while conserving time and typing and preserving freshness of composition. This is the half-page method.

The half-page method is not new with this writer and may be widely known in some circles. It first came to his notice through the preparation by an attorney of a legal textbook which had something of the nature of a catalog. The book was to be set up in several sizes of type to care for quotations, tabulations, footnotes, headings, and sub-headings. The manuscript for such a book would have to be especially neat and orderly. Doubtless many concurrent additions, revisions, subtractions, and some shifting of material had to be made during its writing. The system recommended by the prospective publisher of this text has been found to be a great aid in the writing of scientific manuscripts which have required the handling of large bodies of data and the development of concepts and conclusions as the writing progressed. They also included some material designated for special marginal indentations and type sizes in the printed form.

In the half-page method, the sheet is white bond, or even softer paper, 8.5 by 5.5 inches, with the lines of typing running across the long dimension of the sheet, the result being as though a normal typewriter sheet had been cut in two—crosswise. The distinctive feature is, however, that *each paragraph begins at the top of a page.* Parts of more than a single paragraph do not appear on the same sheet. The usual margins are left at top, bottom, and sides, although not necessarily so much at the bottom as with the full page.

The advantages of this method are immediately evident when we reflect that a paragraph should be a distinct entity, with a unified topic and a noun or substantive clause as its subject, not a relative pronoun which would tie it

[1] Manuscript received, April 11, 1946.

[2] Consulting geologist.

too closely to the preceding paragraph. Thus, a paragraph should not begin: "This is a method which promotes efficiency"; but should read: "The method described in the preceding paragraph is one which promotes efficiency"; or better still, if the context permits: "The method previously described is one," *et cetera.*

An evident advantage of the half-page method is that, where rewriting has to be done here and there in the manuscript, it can be done quickly and the old sheets discarded a half-sheet at a time. Only a half page need, as a rule, be rewritten for any paragraph revision. Paragraphs may be shifted to improve unification. This last item is one which can greatly clarify thinking and eliminate repetitious material including explanatory sentences which otherwise might be needed to connect distant statements.

With the half-page method, the tendency to interline pages extensively with long-hand additions is much reduced for those who indulge that habit to excess. Use of the half page, then, greatly improves the readability of one's own manuscript for himself and lightens the task of the typist who prepares the final, flawless copy.

To take care of many footnotes, tabulations, headings, and other variations of typography, it is possible to use two or more colors of half-sheets. Thus, a blue may be used for headings, pink for footnotes, yellow for extensive quotations, and light green and salmon for the list of illustrations and bibliography.

The extent to which colored sheets are used is based on the estimate of the time saved by their use over that lost in obtaining and preparing them, in selecting them from the paper-holder, and inserting them in the machine. The method has definite advantages in promoting clarity and order in thinking, in composition, and in the final typing.

The decision whether to retain the half-sheet, multi-colored form in the final manuscript or to use it only as an author's composing medium is a separate problem.

The half-page manuscript may not recommend itself to editors as the most convenient form for editorial reading and appraisal. Twice the number of sheets have to be handled, it is not the customary shape for reading, and it can not be scanned as readily as the full-sized sheet. However, for a catalog, or other article of rather formal style, it may have advantages in assisting the editor to indicate the size and style of the various types to be used. It may help the publishing staff to determine the amount of each type to be made available to the typesetters, especially in articles of book length.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 7 (JULY, 1946), PP. 1200-1205

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and are available, for loan, to members and associates.

THE GEOTECTONIC SUBDIVISIONS OF EARTH HISTORY, BY HANS STILLE

REVIEW BY W. A. VER WIEBE[1]
Wichita, Kansas

"The Geotectonic Subdivisions of Earth History," by Hans Stille. 80 pp., 8 illus. Published by the Akademie der Wissenschaften (Berlin, 1944). Separate from *Trans. Prussian Academy of Sciences*, Vol. for 1944. In German.

In this monograph an attempt is made to show the gradual evolution of the earth's crust on the basis of periods of deformation. Because of the significant importance of the pre-Cambrian terranes in the discussion more than half of the pamphlet is given over to a rather detailed description of the old rocks on each continent. The rock types, metamorphism, unconformities, and igneous intrusions of the Laurentian, Fenno-scandian, Siberian, and other parts of the world are fully described. The author finds that the Archean and early Algonkian materials are a natural unit. Furthermore, he finds that these rocks experienced only a few orogenies even though the time span involved is very great.

A great break is present between the old Algonkian rocks and all rocks which were formed later. The Algonkian rocks are separated from the Cambrian rocks in north Scotland by an important angular unconformity in the Assynt district. Therefore, the Assynt period of orogeny serves to separate the pre-Cambrian from the Paleozoic, but should be looked upon only as a minor phase in the post-early Algonkian history of the earth.

There is a striking dissimilarity between the early history of the earth and the later history as revealed in the frequency of orogenic periods. The Archeozoic was closed by an orogenic disturbance of the first order of magnitude. The early Algonkian also ended with a similar disturbance, and furthermore was characterized by several periods of minor disturbance. Up to the end of Silurian time orogenic disturbances are infrequent and of third or fourth order of magnitude. Beginning with the Caledonian disturbance, however, the orogenies occur with much greater frequency.

All told, there are 40 orogenic phases of all magnitudes. As already stated, only four of these came before late Algonkian time. Four of them occurred during the interval of time between the mid-Algonkian break and the end of the Silurian period. About 12 occurred between Silurian and Triassic time while no less than 25 are apportioned to the time between the beginning of the Mesozoic and the present. The length of time between disturbances becomes gradually less. In the Caledonian era (between mid-Algonkian time and end of Silurian time) the interval averages 50 million years. During the Variscan era (Silurian time to Triassic time) the interval between disturbances drops to an average of 12½ years. During the most recent era, called the Alpine era by the author, the interval is only 9 million years. A similar ratio may be calculated for the intervals between orogenies of highest magnitude only. The author closes with the thought that we may be rapidly

[1] Professor of geology, University of Wichita. Review received, June 1, 1946.

approaching a final consolidation condition of the earth as a whole, but calls attention to the fact that twice previously we had similar conditions.

PRINCIPLES OF MICROPALEONTOLOGY, BY M. F. GLAESSNER

REVIEW BY BROOKS F. ELLIS[1]
New York, N. Y.

Principles of Micropaleontology, by M. F. Glaessner. 283 pp., 14 pls., 7 tables. Melbourne University Press (1945). Price, 46s.

This new handbook for micropaleontologists developed out of a series of lectures given by the author at the University of Moscow in 1936–1937. The work started at Moscow was continued under the sponsorship of the Anglo-Iranian Oil Company, and later that of the Standard Vacuum Oil Company of New York. It was not until 1943, however, that the manuscript was completed; and the published work finally appeared in September, 1945.

Micropaleontologists everywhere will welcome the appearance of this excellently illustrated and documented manual. Here at last is a publication dealing with substantially all the major groups of microfossils. Radiolaria, calpionellids, ostracods, diatoms, sponge spicules, conodonts and scolecodonts, spores and pollen are all covered. As might be expected, however, the major portion of the work deals with the Foraminifera. After outlining the history of micropaleontology, the author classifies microfossils and discusses the various smaller groups. Of these, the ostracods and conodonts are treated at some length. This is followed by a section dealing with collecting and studying microfossils. Techniques of collecting both surface and well samples are discussed as also are packing and labeling. Various methods of disintegrating both hard rock samples and clays and clay marls are recommended. Special methods involving differential heating and chemical reagents are indicated for various rock types. The techniques of washing, separating, mounting, etching, and sectioning are simply and adequately described.

The discussion of the structure and life history of living Foraminifera is particularly valuable, as it treats of a phase of the work all too frequently neglected by many micropaleontologists. This section of the manual is particularly well documented.

In discussing the morphology of the test, the author takes up wall material, arrangement of chambers, aperture, shape of the test, canal systems, and ornamentation in the order indicated, which he considers to be the order of importance. Principles of classification are discussed at length, and various classifications are reviewed and evaluated. Glaessner's own classification is based on the following points.

1. The non-septate forms are more primitive than the septate.
2. The higher, or septate, spirally coiled arenaceous Foraminifera form a well defined group.
3. The Fusulinidae are derived directly from the Endothyridae.
4. The different lines of the porcellaneous Foraminifera have a common origin in coiled non-septate forms.
5. The Polymorphinidae are derived from the Laginidae, but there is no clear evidence concerning the origin of this family.
6. The Cassidulinidae and Ellipsoidinidae are related to the Buliminidae, which can be traced back to a trochospiral ancestral form. Most of the other smaller, calcareous, perforate Foraminifera are clearly derived from rotaloid ancestors.

[1] Department of Micropaleontology, the American Museum of Natural History. Review received, June 7, 1946.

7. Most of the larger, calcareous, perforate Foraminifera, including Siderolites, Orbitoides, Lepidocyclina, Miogypsina, and probably the Nummulites developed from a number of different, but closely interrelated small rotaloid ancestors.

In accordance with these principles, the Foraminifera are divided into seven superfamilies. These are: Astrorhizidea, Lituolidea, Endothyridea, Miliolidea, Lagenidea, Buliminidea, and Rotaliidea. In all, sixteen families are recognized as against forty-nine families in Cushman's classification of 1940 and thirty-five in Galloway's classification of 1933.

Paleoecology and the stratigraphic sequence of microfaunas constitute an important part of this work. Methods and principles of biostratigraphic correlation, regional stratigraphic correlation, as well as long-range determination of geologic age, are all fully discussed and illustrated. The section on the application of micropaleontology to petroleum geology as practiced in Europe, Asia, and adjoining regions should be of interest especially to American workers.

Listing of laboratory and field equipment, as well as the presentation of advantageous laboratory layouts will be helpful to those responsible for equipping and maintaining laboratories.

The appendix contains a synopsis of the author's revised classification of Foraminifera with the stratigraphic range of genera indicated, as well as a comparison of this classification with that given by Cushman in 1940. A well selected bibliography adds greatly to the value of the work.

RECENT PUBLICATIONS

ALABAMA-MISSISSIPPI

"Geologic Map of the Tertiary Formations in Alabama," by F. Stearns MacNeil. *U. S. Geol. Survey Prelim. Map 45,* Oil and Gas Investig. Ser. (May 1946). Single sheet, 30×37 inches. Scale, 1 inch equals 8 miles. For sale by Director, Geological Survey, Washington 25, D. C. Price, $0.40.

"Correlation of the Pre-Selma Upper Cretaceous Formations between Tuscaloosa County, Alabama, and Neshoba County, Mississippi," by D. Hoye Eargle. *U. S. Geol. Survey Prelim. Chart 20,* Oil and Gas Investig. Ser. (May, 1946). Single sheet, 25×38 inches. May be bought from Director, Geological Survey, Washington 25, D. C. Price, $0.30.

"Summary of the Midway and Wilcox Stratigraphy in Alabama and Mississippi," by F. Stearns MacNeil. *U. S. Geol. Survey Prelim. Rept. 3-195,* Strategic Minerals Investig. Ser. (May, 1946). With correlation chart. Obtainable from Director, Geological Survey, Washington 25, D. C. Price, $0.50.

ALABAMA-TEXAS

"Correlation of the Outcropping Upper Cretaceous Formations in Alabama and Texas," by Watson H. Monroe. *U. S. Geol. Survey Chart 23,* Oil and Gas Investig. Ser. (June, 1946). Single sheet, 21×26 inches. With brief text on same sheet. May be purchased from Director, Geological Survey, Washington 25, D. C. Price, $0.20.

APPALACHIANS

*"Subsurface Temperatures and Viscosity Temperature Relationships of Crude Oils in Appalachian Region," by E. M. Tignor. *Producers Monthly,* Vol. 10, No. 7 (Bradford, Pennsylvania, May, 1946), pp. 12–18; 8 figs., 2 tables.

ARGENTINA

*"Contribucion al Conocimiento Geologico de la Precordillera Sanjuanino-Mendocina" (Contribution to the Geology of the San Juan-Mendoza Pre-Cordillera), by Osvaldo Bracaccini. *Bol. Inform. Petrol.*, Vol. 23, No. 258 (Y.P.F., Buenos Aires, February, 1946), pp. 81–105; 7 figs., 2 pls. In Spanish.

BAHAMAS

*"Bahamas Oil Search Begins," Anon. *Oil Weekly*, Vol. 122, No. 1 (Houston, June 3, 1946), International Section, pp. 9–10; 2 photographs, 1 map.

CALIFORNIA

*"Crystalline Rocks of Southern California," by William J. Miller. *Bull. Geol. Soc. America*, Vol. 57, No. 5 (New York, May, 1946), pp. 457–542; 7 pls.

*"History of Gas Conservation in California," by E. Huguenin. *California Oil Fields*, Vol. 31, No. 1 (San Francisco, January-June, 1945—issued in 1946), pp. 3–19.

*"Shiells Canyon Area of Bardsdale Field," by William C. Bailey. *Ibid.*, pp. 19–26; 4 pls.

*"Permian Fusulinids of California," by M. L. Thompson, Harry E. Wheeler, and John C. Hazzard. *Geol. Soc. America Mem. 17* (New York, April, 1946). 77 pp., 18 pls., 4 figs.

CANADA

"Geological Reconnaissance along the Canol Road, from Teslin River to Macmillan Pass, Yukon," by E. D. Kindle. *Canada Geol. Survey Paper 45–21* (Ottawa, 1946). 2d ed. 29 mimeographed pp., 1 blue-line-print map (approx. 32×36 inches; scale, 1 inch equals 4 miles).

CHINA

"Middle and Upper Carboniferous Stratigraphy of Western Kansu," by T. C. Tseng. *Bull. Geol. Soc. China*, Vol. 24, Nos. 1–2 (Pehpei, Chungking, Szechuan, June, 1944; printed in 1945), pp. 37–46; 2 pls. In English.

"On Tectonic History in Regions East of the Tibetan Plateau from Kansu to Yunnan," by L. T. Yeh. *Ibid.*, pp. 53–56; 2 pls.

*"On Major Tectonic Forms of China," by T. K. Huang. *National Geol. Survey of China Geol. Memoirs*, Ser. A, No. 20 (Pehpei, Chungking, December, 1945). 165 pp., 8 pls. In English. 13 pp. in Chinese.

COLOMBIA

"Los vertebrados del Terciario continental Colombiano" (Vertebrates of Continental Tertiary in Colombia), by Jose Royo y Gomez. *Revista de la Acad. Colombiano de Ciencias Exactas, Fisico-Quimicas y Naturales*, Vol. 6, No. 24 (Bogota, 1945), pp. 496–512; 7 figs., 5 pls.

COLORADO-KANSAS

*"Subsurface Geologic Cross Section from Ness County, Kansas, to Lincoln County, Colorado," by John C. Maher. *Kansas Geol. Survey Prelim. Cross Section 2*, Oil and Gas Investig. (Lawrence, 1946). 13 pp., 1 fig., 1 folded section. Prepared by U. S. Geological Survey with cooperation of Kansas Geological Survey.

GENERAL

*"A Theory on Occurrence of Salt Domes," by Raymond D. Shrewsbury. *Oil Weekly*, Vol. 122, No. 1 (Houston, June 3, 1946), pp. 36–39; 5 figs.

*"Airborne Magnetometer Expedites Geophysical Surveys," by Gordon B. Nicholson. *Ibid.*, pp. 29–32; 1 map, 3 photographs.

*"Airborne Magnetometer," by E. A. Eckhardt. *Oil and Gas Jour.*, Vol. 45, No. 5 (Tulsa, June 8, 1946), pp. 78–79, 91–92; 2 photographs, 1 fig.

*"Penetration Rates in Hard Formation Drilling," by J. E. Warren and R. B. Schabarum. *Ibid.*, pp. 82–87; 5 figs., 1 table.

*"The Meaning of Petroleum Reserve Estimates," by Richard J. Gonzalez. *Oil Weekly*, Vol. 122, No. 2 (Houston, June 10, 1946), pp. 49–50.

*American Petroleum Interests in Foreign Countries," *Hearings of U. S. Senate Special Committee Investigating Petroleum Resources, June 27–28, 1945 (1946)*. Includes (1) brief history of foreign oil development, by countries, over a period of 85 years, and (2) oil resources developed by American petroleum industry abroad. May be purchased from Supt. of Documents, Govt. Printing Office, Washington 25, D. C. 500 pp. Price, $1.00.

Principles of Field and Mining Geology, by Donald Forrester. 647 pp. illus. 5.625 ×5.625 inches. John Wiley and Sons, Inc., 440 Fourth Avenue, New York 16, N. Y. Price, $7.00.

"Petroleum Requirements—Postwar," *5th Ser. of Hearing of U. S. Senate Committee Investigating Petroleum Resources*. 119 pp. Among the subjects are: (a) Supply and Demand in Foreign Areas, (b) Forecast of Future Requirements in the United States, (c) Exploration, Development and Conservation of Present Petroleum Reserves, and (d) Compilations and graphs of the petroleum industry growth and accomplishments. For sale by Supt. of Documents, Govt. Printing Office, Washington, D. C. Price, $0.25.

ITALY

"Ricerche micropaleontologiche e stratigrafiche sulla scaglia e sul Flysch cretacici nei dintorni Balerna (Canton Ticino)," by Gandolfi R. *Rivista Italiana di Paleontologia*, Memoria IV (Milano, via Botticelli, 23). Price, Lire 800.

KANSAS

*"Petrographic Comparison of Pliocene and Pleistocene Volcanic Ash from Western Kansas," by Ada Swineford and John C. Frye. *Kansas Geol. Survey Bull. 64* (Lawrence, April 15, 1946). 32 pp., 4 figs., 4 tables.

*"Review of Studies of Pleistocene Deposits in Kansas," by John C. Frye. *Amer. Jour. Sci.*, Vol. 244, No. 6 (New Haven, June, 1946), pp. 403–16; 1 fig.

MEXICO

*"Geology of the Region of Cuchillo Parado, Chihuahua," by Agustin Sevilla Segura. *Ingenieria*, Vol. 19, No. 8 (Mexico, D. F., August, 1945), pp. 248–51. Jurassic Peninsula and its relation to possible accumulation of hydrocarbons. In Spanish.

MICHIGAN

*"Pre-Historic Mackinac Island," by George M. Stanley. *Michigan Geol. Survey Pub. 43*, Geol. Ser. 36 (Lansing, 1945). 74 pp., frontispiece, 31 figs., and folded map. Price, $1.00.

*"Geology of the Mackinac Straits Region and Subsurface Geology of Northern Southern Peninsula," by Kenneth K. Landes, George M. Ehlers, and George M. Stanley. *Ibid.*, *Pub. 44*, Geol. Ser. 37. 204 pp., frontispiece, 20 pls., 14 figs. Price, $1.00.

NEW MEXICO

*"Tertiary and Quaternary Geology of the Lower Rio Puerco Area, New Mexico," by Herbert E. Wright, Jr. *Bull. Geol. Soc. America*, Vol. 57, No. 5 (New York, May, 1946), pp. 383–456; 10 pls., 12 figs.

OKLAHOMA

"Maps of Northeastern Oklahoma and Parts of Adjacent States Showing Thickness and Subsurface Distribution of Lower Ordovician and Upper Cambrian Rocks below the Simpson Group," by H. Andrew Ireland assisted by John H. Warren. *U. S. Geol. Survey Prelim. Map 52,* Oil and Gas Investig. Ser. (May, 1946). Single sheet, 37×43 inches. May be bought from Director, Geological Survey, Washington 25, D. C.; Federal Building, Tulsa, Oklahoma; and Boston Building, Denver, Colorado. Price, $0.60.

PARAGUAY

*"Paraguay's First Wildcat to Spud in Soon," by Gilbert M. Wilson. *Oil Weekly,* Vol. 122, No. 1 (Houston, June 3, 1946), International Section, pp. 28–29; 1 map.

PENNSYLVANIA

*"Present Work of the Pennsylvania Geological Survey in the Oil Fields of Pennsylvania," by Charles R. Fettke. *Producers Monthly,* Vol. 10, No. 7 (Bradford, May, 1946), pp. 23–27; 6 photographs.

PERU

*"Geological Investigations around Lake Titicaca," by Norman D. Newell. *Amer. Jour. Sci.,* Vol. 244, No. 5 (New Haven, Connecticut, May, 1946), pp. 357–66; 3 figs.

*"Preliminary Note on Geologic Studies of the Pacific Slope of Southern Peru," by William F. Jenks. *Ibid.,* pp. 367–72.

WYOMING

*"Geology of the Northwestern Wind River Mountains, Wyoming," by Charles Laurence Baker. *Bull. Geol. Soc. America,* Vol. 57, No. 6 (New York, June, 1946), pp. 565–96; 11 pls., 1 fig.

DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 20, No. 3 (May, 1946).

"Comanche Echinoids," by C. Wythe Cooke.

"New Washita Foraminifera," by Alfred R. Loeblich, Jr., and Helen Tappan.

"A Pleistocene *Ovis Canadensis* from New Mexico," by J. Willis Stovall.

"Fossil Egg Capsules of Chimaeroid Fishes," by Roland W. Brown.

"A New Species of *Dolatocrinus* from the Traverse (Middle Devonian) of Michigan," by Edwin Kirk.

"*Corythocrinus*, a New Inadunate Crinoid Genus from the Lower Mississippian," by Edwin Kirk.

"Intervallum Strcuture of *Cambrocyathus Amourensis*," by Vladimir J. Okulitch.

**Journal of Sedimentary Petrology* (Tulsa, Oklahoma), Vol. 16, No. 1 (April, 1946).

"A Comparison of Three Sieve Shakers," by Ada Swineford and Frances Swineford.

"Carnallite-filled Mud Cracks in Salt Clay," by Ralph H. King.

"Volcanic Sediments in North Texas," by Raymond Sidwell and Richmond L. Bronaugh.

"Interpretation of the Results of Mechanical Analyses," by D. J. Doeglas.

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THE ASSOCIATION ROUND TABLE

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REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL: PHILIP B. KING (1949)

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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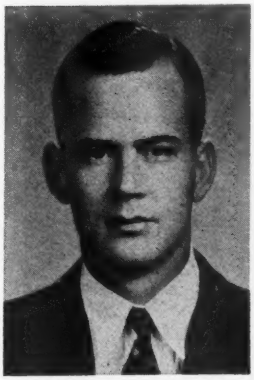
HOUSTON GEOLOGICAL SOCIETY STUDENT AWARDS

The Houston Geological Society Student Awards for 1946 have been announced: the recipients are PAUL D. GRAHAM, geologist, and JAMES W. AMYX, petroleum engineer, both of Texas Agricultural and Mechanical College, College Station, Texas. These student awards, first given in 1940, were interrupted in 1942 by the war, and the 1946 awards are the first since that time. Each award is a 2-year paid-up associate membership in the A.A.P.G.: one given to a student in the geology department and one to a student in the petroleum engineering department of Texas A. & M. Selection is made from papers presented at the award program. Graham's paper was "Problem of Paleozoic Stratigraphy in the Chinati Mountains," and Amyx wrote on "Underground Storage of Natural Gas."




PAUL D. GRAHAM JAMES W. AMYX

PAUL D. GRAHAM

Bachelor of Science (geology, 50 hours), May, 1946, Agricultural and Mechanical College of Texas, College Station, Texas (1939–1943 and February, 1946–May, 1946). Born, October 21, 1920, Winters, Texas. Preparatory: San Angelo High School, San Angelo, Texas (1936–1939). Experience: Geology Department, A. & M. College of Texas (September, 1941–July, 1942) Army (1943–1945), served 20 months in E. T. O. with 9th Troop Carrier Command, and McAlister Trucking Company (1945–1946). Member: A. & M. Geology Club; A. & M. Band (1939–1943).

JAMES W. AMYX

Bachelor of Science in Petroleum Engineering (geology, 18 hours), June, 1946, Agricultural and Mechanical College of Texas, College Station, Texas (1938–1942, and 1945–1946). Born, November 5, 1921, Eastland, Texas. Preparatory: Burkburnett High School, Burkburnett, Texas. Experience: summer, 1938, roughneck; summer, 1941, clerk, U.S.E.D.; Captain, Infantry Reserve. Military decorations: Silver Star, Bronze Star with Cluster, Purple Heart, Combat Infantry Badge.

ELMER W. ELLSWORTH APPOINTED ASSISTANT BUSINESS MANAGER

Lt. Col. Elmer W. Ellsworth (sometimes known as "Lefty"), a man of recognized geological ability and a member of the Association since 1936, will join our headquarters staff on August 15, assuming the duties of assistant business manager and reporting directly to J. P. D. Hull.

Ellsworth returned from the Pacific Theater, having entered the service in 1942, serving as Chief of the Information Collecting and Record Section of the A.A.F. Arctic, Desert and Tropical Information Center until October, 1945. Subsequently, until his departure from the Orient on May 24, 1946, he acted in the capacity of Technical Supervisor and Korean Affairs Officer of the National Resources Section, GHQ-SCAP, serving directly under Colonel Hubert G. Schenck, Chief of the National Resources Section. During this time, he assisted in coordinating the activities of the Agriculture, Forestry, Mining and Geology, and Fisheries Divisions, and insured proper initiation and completion of projects necessary to fulfill the responsibilities of the National Resources Section in Korea.

He received an A.B. in Geology from the University of Wisconsin in 1929, and a Ph.D. from Stanford University in April, 1933. Previous to entering the Army, he served in various capacities as field geologist, geophysicist, and consultant on geological, mining, and petroleum problems in various parts of the United States and Canada.

Listed in *American Men of Science*, he is the author of the following papers:

"The Varved Clay Deposits at Waupaca, Wis.," *Trans. Wisconsin Acad. of Sciences* (1930)

ELMER W. ELLSWORTH

"The Glacial Lake Clays of Wisconsin," *ibid.* (1931)

"Tracing Buried Gold-Bearing Channel Deposits with the Magnetometer," *Ann. Rept. California State Mineralogist* (1933)

"The Tin Deposits of Alabama," *U. S. Geol. Survey* (1934)

With Eliot Blackwelder as senior author: "Pleistocene History of the Afton Basin of the Mohave Desert," *Amer. Acad. of Sciences* (1935) (Based on Ph.D. dissertation of junior author)

MID-YEAR MEETING, BILOXI, MISSISSIPPI
OCTOBER 24, 25, 26, 1946

The executive committee has accepted the invitation of the Mississippi Geological Society to sponsor a mid-year meeting at Biloxi, Mississippi, on October 24, 25, and 26. The Buena Vista Hotel at Biloxi is to be headquarters and other hotels at Biloxi and at Gulfport (6½ miles away) will assist. All requests for hotel accommodations should be made with the Buena Vista Hotel, Biloxi.

The technical program is planned to present the general geologic features of the southeastern states, covering stratigraphy from early Paleozoic to Recent, tectonics and structure of the region, the Mississippi salt basin, and detailed papers on outstanding fields.

Frederic F. Mellen, president of the Mississippi Geological Society, at Jackson, announces the appointment of J. B. Storey, immediate past-president of the Society, as chairman of arrangements. Further announcements will be made.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 7 (JULY, 1946), PP. 1213-1216, 1 FIG.

MEMORIAL

WILLIAM FRANCIS CHISHOLM
(1886–1944)

William Francis Chisholm was born in Cambridge, Massachusetts, on December 2, 1886. His early education was at St. Mary's Grade School and Rindge Technical High School at Cambridge. Following this, he obtained his B.S. degree at St. Francis Xavier University, Antigonish, Nova Scotia, from which he graduated in 1915. He continued there for two more years, doing post-graduate work, principally in biology and research methods. During his period of education, he worked on various drafting, cost accounting, and production efficiency projects, in order to pay his way through the university. He also taught at various summer training schools, and public and night schools at various times, and at St. Francis Xavier University, where he taught a wide variety of scientific subjects, as well as English, debating, and public speaking.

On June 7, 1917, he enlisted as a private in the 101st Engineers, U. S. Army. On April 28, 1919, he returned from overseas and was honorably discharged as a first lieutenant. He taught a variety of engineering subjects in the 2nd Engineering School at Chatillon-sur-Seine, France, and also served in forward areas and in road and barrack construction.

His office and technical experience included a short time with the Canadian Geological Survey, and a period from 1919 through 1926 in Shreveport with three major oil companies, as field and office geologist. During this period, he worked for Sinclair, Arkansas Fuel, and Roxana, and became well known and well liked by the entire oil fraternity in the Shreveport district. His mature judgment and varied experience were the basis for the sound advice he was always willing to impart to the younger men of our profession. In December, 1926, he was appointed director of the Minerals Division of the Louisiana Department of Conservation, where for three years he supervised enforcement of mineral laws, issuance of well permits and spacing regulations, enforcement of stream-pollution laws, and control of wild wells. Bill was always highly respected by the oil fraternity, and is rated as one of the best directors this division ever had.

For the next four and one-half years, he was district superintendent for Halliburton Oil Well Cementing Company in the southeastern states, in which capacity, he became even better known and regarded by all with whom he came in contact. After one year in independent sales promotion of oil-field equipment, he acted for one year as safety engineer for the W.P.A. in the Fourth District, Louisiana. From 1939 until the time of his death, April 11, 1944, he was back with the Louisiana Department of Conservation as chief engineer and as director of the Division of Research and Statistics. In this capacity, his education and experience in the various sciences, including chemistry, geology, biology, and general research, made him particularly valuable to the State and the country in general.

Bill was a member of the following scientific societies.

Arkansas Mineralogical Society (honorary life member)
American Association of Petroleum Geologists
Louisiana Academy of Sciences (charter member)
Shreveport Geological Society (former president)
American Mining Congress (served as member of board of governors—Southern Division)
American Institute of Mining and Metallurgical Engineers
International Association of Fish, Game and Conservation Commissioners
American Fisheries Society

In addition, he was a member of the American Legion, Forty and Eight, Veterans of

Foreign Wars, Military Order of the World War (charter member at Baton Rouge), Rotary, and Knights of Columbus. He took an active part in all of these organizations, particularly on projects which had the betterment of the community or the nation as their objects.

Included in his achievements was the fine family he fathered, provided for, and educated. On January 14, 1920, he married Esther O'Connor of Cambridge, and shortly afterward came to Shreveport, where he lived, worked, and made many friends. His wife was always the power which guided Bill to better things. Four daughters, Constance, Esther, Alma, and Helen, were born in the early 1920's, and they all received a higher education, mainly at Louisiana State University. He was a devoted father, his family's interests always being first in his thoughts.

Bill was a very public-spirited citizen, and took an active interest in a wide variety of public and group undertakings. He was particularly active in the veterans' organizations, always striving to make them a means of bettering the general conditions in which we live. The foregoing summary reveals only a small part of the fine things he accomplished in this world. It would be difficult to pick a man in Louisiana with higher ideals, more Christian virtues, more real, though sometimes unknown, accomplishments. He was widely known and highly regarded by his friends, by his scientific associates, and by the general public. Any cause he undertook was carried on with quiet zeal and steadfast determination. He never wavered from any cause he once agreed to carry forward.

The citizens of Louisiana, the geological profession, and the scientific world as a whole, suffered a great loss when Bill left us. However, his family, his friends, and his scientific associates may look with pride on his many accomplishments, and on his life, so full of quiet help and encouragement to others.

G. D. THOMAS

SHREVEPORT, LOUISIANA
May 28, 1946

ROBERT HENDEE SMITH
(1916–1946)

The accidental death of Robert Hendee Smith, as a result of an automobile accident on the evening of March 26, 1946, has saddened and shocked all who knew him. The tragedy occurred while Bob was returning to Jackson, Mississippi, from a business trip to Shreveport, Louisiana, for The Texas Company by whom he was employed as a geologist.

Robert Hendee Smith was born on March 22, 1916, in New York City, the second son of Charles Hendee Smith, a physician, and Grace Wales Smith. In 1941 Bob, or "Smokey," as he was known to his friends, married Rosemary Quinn of Lake Charles, Louisiana. He received his primary education at the Allen Stevenson School in New York City and his secondary education at the Kent School in Connecticut from which he graduated in 1934. He entered Princeton University in 1934 where he majored in biology. His scholastic record there was outstanding and it was during this period that he first developed an interest in paleontology, a field which later proved to be his major interest. His senior thesis in the department of biology was the "Evolution of the Genus Papilio, a Study of the North and South American Members of a Genus in the Lepidoptera." During his college years, he earned a major portion of his expenses by part-time work which, coupled with a heavy schedule of class and laboratory work, testifies to the determination with which he always met problems facing him. While at Princeton his interest in science led him afield each summer, one being spent at the Marine Biological Laboratory at Bar Harbor, Maine, another on a butterfly collecting expedition to Florida, and still another at the Princeton Geological Field Camp at Red Lodge, Montana. He graduated from

ROBERT HENDEE SMITH

Princeton in 1938 and entered Louisiana State University as a graduate student in geology in the fall of the same year. He received the degree of Master of Science from Louisiana State in 1940. Following the conferring of this degree, Smokey remained at the University to study for the degree of Doctor of Philosophy. In 1945 he passed the general examination for this degree with distinction. At the time of his death, Smokey was completing the work on his dissertation. Because of the fundamental nature of this work and its nearness to completion, the degree of Doctor of Philosophy was conferred posthumously by Louisiana State University on May 27, 1946.

Smokey was blessed with robust physical health. While at Kent School his fine physique enabled him to develop into a football player of some note. At Princeton he supplemented his scholastic abilities with a successful record of athletic achievement as a member of the wrestling team.

Bob was an enthusiastic collector even during his youthful years. Everything that caught his collecting fancy was thoroughly explored, from stamps and coins to insects and birds' eggs. The tireless industry and ambition which he exhibited in pursuit of his various collecting objectives left a strong imprint on his character. The fine fossil collecting localities available to him in the Gulf Coast region and neighboring areas kept Smokey in a continual state of enthusiasm in planning and making collecting trips and working over his samples. This collecting activity, during the years he spent in school and in the profession, resulted in numerous excellent paleontologic assemblages from most of the Tertiary type localities of the Gulf and Atlantic Coastal Plains. Some of this material now forms part of the fossil collections in the Museum of Paleontology of the School of Geology at Louisiana State University. Another considerable collection has been divided between the University of Houston and Princeton University where it forms the nucleus for memorial collections under the name of Robert Hendee Smith. Those of us who lived close to Smokey during those years he spent at the University will not soon forget the strongly imprinted picture of his departure on, or return from, one of his many collecting trips.

Smokey's professional activities in the field of geology were varied. Between 1939 and 1941 he worked as a field assistant for the Louisiana Geological Survey and the Florida Geological Survey and was employed for short periods by various oil companies. In 1941 he accepted a geological position with the Mississippi River Commission where he was associated with a group investigating the geology of the Mississippi alluvial valley and was particularly active in paleontologic and stratigraphic studies and physiographic interpretation of the alluvial valley. He remained with the Mississippi River Commission until the project was completed. In 1945 he accepted a position as geologist with The Texas Company and was assigned to the Jackson, Mississippi, office. He was working in this capacity at the time of his death.

In spite of his all too short career, Smokey's research efforts were fruitful. In 1940 he published a paper in the *Bulletin* of the American Association of Petroleum Geologists titled "Micropaleontology of a Deep Well at Niceville, Okaloosa County, Florida." His next work was his Master's thesis, "Fauna of the White Creek Miocene, Walton County, Florida." He made extensive studies of the stratigraphy of the Little Stave Creek section near Jackson, Alabama, and published a section and a map of this locality in the *Guidebook* of the May, 1944, field trip of the Mississippi Geological Society. Another of his research projects, read by title only before the Denver meeting of the Society of Economic Paleontologists in 1942, was titled "New Species of Discocyclina (Aktenocyclina) from Alabama and Texas." Smokey's work reveals the fine ability and keen insight which so characterized him to his associates. With his death the profession has lost one of its truly brilliant young minds.

Smokey is survived by his widow, the former Rosemary Quinn, of Lake Charles, Louisiana, three children, Marguerite, David, and Marianne, his parents, Dr. and Mrs. Charles Hendee Smith, of New Brunswick, New Jersey, and a brother, Dr. Dewitt Hendee Smith.

BENJAMIN A. TATOR

BATON ROUGE, LOUISIANA
May, 1946

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 7 (JULY, 1946), PP. 1217-1220

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

NATIONAL ROSTER

The National Roster of Scientific and Specialized Personnel was established in 1940 as a part of the Federal Government, and served during the war period as a central clearing house for information concerning scientifically and technically trained personnel. It now operates under George A. Works, director, as a section of the United States Employment Service of the Department of Labor, Washington 25, D. C. During the war period, the Roster's inventory of the nation's professionally skilled manpower was of material assistance in assuring a high degree of utilization in the war program of the nation's highly trained personnel.

With scientific research and development emerging as basic elements of national security, the role of the Roster has assumed important peacetime significance. A complete analytical listing of the names, locations, and specialized skills of our scientific manpower is essential in order that information concerning the extent and distribution of the country's scientific talent may be readily available. It is especially important that there be a central clearing house which is in a position to maintain information and statistics concerning scientific and professional personnel, and provide a basis for locating highly skilled individuals who may from time to time be called upon to furnish advice to the Government on scientific and professional matters.

The National Roster also provides a placement service available both to employers and employees to assist as far as possible in bringing about the location of specially trained personnel in positions commensurate with their skills. Registration with the Roster, however, is not considered an application for employment, and placement service is rendered upon only specific request.

The Geological Society of America announces that copies of the Proceedings of the Conference on Training in Geology are to be available, without charge, by writing HENRY R. ALDRICH, secretary, Geological Society of America, 419 West 117th Street, New York 27, N. Y. The brochure contains the proceedings of the conferences at Pittsburgh, December, 1945, and at Chicago, April, 1946.

ELMER W. ELLSWORTH, consulting geologist of Centralia, Illinois, has been appointed assistant business manager of the Association, with headquarters at Tulsa, Oklahoma.

The Shreveport (Louisiana) Geological Society elected new officers, June 11: president, T. H. PHILPOTT, Carter Oil Company; vice-president, BRAME WOMACK, Sohio Petroleum Company; secretary-treasurer, J. ED. LYTLE, Union Producing Company.

The Panhandle Geological Society sponsored a three-day field trip starting May 16 to the Front Range of the Rocky Mountains in southeastern Colorado including a trip up the Dry Cimarron Valley in the Oklahoma Panhandle and northern New Mexico. Plans and preparation for the trip were worked out by R. K. LANYON and T. G. GLASS in conjunction with a field-trip committee composed of G. C. CLARK, L. M. OLES, HARRY M. BRITT, FRED MASON, and L. H. THAWLEY. The leaders on the trip were W. F. EARL, Ohio Oil Company, Tulsa, Oklahoma, DON B. GOULD, Colorado College, Colorado Springs, Colorado, CHARLES S. LAVINGTON, consultant, Denver, Colorado.

Harold W. Haight has been named vice-president and director of the Creole Petroleum Corporation, succeeding John L. Kalb. Haight has been production manager for the Creole in Venezuela and has been with the Standard Oil Company (New Jersey) and affiliates since 1927. Kalb has been with the company more than 20 years.

Frederick J. Smith has been transferred from Jackson, Mississippi, to the Seminole, Oklahoma, district of the Sinclair Prairie Oil Company.

Harold W. Hoots, chief geologist for the Richland Oil Corporation, Los Angeles, California, has resigned and opened a consulting office. He is succeeded by Rollin Eckis, formerly assistant chief geologist.

Oliver J. Todd is vice-president of the Sabine Development Company, Houston, Texas.

N. R. Lamb has opened a field office at Artesia for the New Mexico Bureau of Mines and Mineral Resources, as announced by Robert L. Bates, chief of the Oil and Gas Division, Socorro. The State Bureau, E. C. Anderson, director, is located at Socorro.

The Tulsa Geological Society has elected officers for the new administrative year beginning in August: president, John G. Bartram, Stanolind Oil and Gas Company; 1st vice-president, Russell S. Tarr, independent; 2d vice-president, John C. Maher, United States Geological Survey; secretary-treasurer, John R. Crain, Ashland Oil and Refining Company; editor, Robert F. Walters, Gulf Oil Corporation. Members of the Society council are: Glenn D. Hawkins, consulting; Sam H. Woods, Sun Oil Company; V. C. Scott, Texas Company; A. N. Murray, Tulsa, University.

The Houston Geological Society recently elected officers for the year: president, Shapleigh G. Gray, independent and consulting geologist; vice-president, Charles H. Sample, of the J. M. Huber Corporation; secretary, A. F. Childers, Gulf Oil Corporation; treasurer, Wayne Z. Burkhead, Union Oil Company of California. Members of the advisory committee are: R. L. Beckelhymer, independent and consulting geologist; J. A. Culberson, Continental Oil Company; E. L. Earl, Crown Central Petroleum Company; Olin G. Bell, Humble Oil and Refining Company.

W. H. Twenhofel is engaged in work in Newfoundland this summer, for the Newfoundland Geological Survey.

William M. Cogen, of Los Angeles, California, a Major with extensive experience as aerial photo interpreter, C. B. I. Theater, during the World War, has returned to the Shell Oil Company, Inc., Houston, Texas.

Sam Zimmerman has been transferred from the Carter Oil Company at Tulsa, Oklahoma, to the Standard Oil Company of Egypt at Cairo, where he will be chief geophysicist.

The Association will hold a mid-year meeting at Biloxi, Mississippi, October 24–26, inclusive, under the sponsorship of the Mississippi Geological Society, of Jackson.

The newly organized Pacific Petroleum Chapter of the A.I.M.E., of which William W. Porter II is chairman, held its first meeting at the University Club, Los Angeles on June 19.

Hubert G. Schenck and Thomas A. Hendricks spent parts of May and June in Korea and Manchuria as members of Ambassador E. E. Pauley's Reparations Mission. They will return to Tokyo upon completion of the present assignment. John Hurndall is a permanent member of the Mission.

HENRY C. CORTES, who has been director of geophysical exploration for the Magnolia Petroleum Company, Dallas, Texas, is now assistant manager of the land and exploration department. PAUL E. NASH succeeds Cortes as director of geophysical exploration and J. C. MENAFEE is assistant to Nash.

The geological forum of the Pacific Section of the A.A.P.G. presented the following program on May 27: "Subsidence of Terminal Island, 1933–1946," by JAMES GILLULY; "Cretaceous Correlations in California," by W. P. POPENOE; and "The Tertiary in the Neighborhood of Barstow," by CORDELL DURRELL. All the speakers are on the geological staff of the University of California, at Los Angeles.

LEON F. RUSS, SR., LEON F. RUSS, JR., and SEMP RUSS are incorporators of the Russ Oil Corporation with headquarters at San Antonio, Texas.

POSITIONS OPEN—GEOLOGIST

The United States Civil Service Commission announces an examination for probational appointment to the position of Geologist. Salaries are $2,644 and $3,397 a year. Options in subjects are: Mineralogy and Petrology, Sedimentation, Stratigraphy, Geomorphology and Glaciology, Ground-Water Geology, Geology of Fuels, Geology of Metallic and Non-Metallic Mineral Deposits. Applications must be received in the U. S. Civil Service Commission, Washington, D. C., not later than August 7, 1946. Most positions are located in Washington, D. C., and throughout the United States. A few positions may be filled in the territories and possessions of the United States and in foreign countries. The vacancies to be filled from the lists established as a result of this examination exist in the Geological Survey in the Department of the Interior and in the Bureau of Plant Industry and the Soil Conservation Service in the Department of Agriculture. The lists may also be used to fill vacancies in other Government agencies. Application card Form 5000-AB may be obtained at any first- or second-class post office, except in cities where a U.S. Civil Service regional office is located. In such cities this form may be obtained at the U.S. Civil Service regional office. The form may also be obtained from the U.S. Civil Service Commission, Washington 25, D.C.

SOUTH AMERICAN PETROLEUM CONGRESS

The First South American Petroleum Congress will be held in Lima, Peru, the first week in March, 1947. The Instituto Sudamericano del Petroleo has extended an invitation to the members of the A.A.P.G. to attend this meeting and to participate in the discussions. The program planned for this meeting will be of particular interest to A.A.P.G. members concerned with foreign exploration and development, and any members wishing to attend may obtain further information by addressing the Peruvian Section of the I.S.A.P., P.O. Box 889, Lima, or the Executive Committee of the I.S.A.P., P.O. Box 414, Montevideo, Uruguay.

GEOLOGY AS A PROFESSION

The Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C., has for distribution at a price of ten cents, a small booklet entitled "Geology as a Profession," Vocational Booklet No. 1, which was prepared by the National Roster of Scientific and Specialized Personnel. The author is Miss Ann Richards Taylor, working under the direction of W. T. Read, chief of the Research Section, with the advice and assistance of many geologists. The booklet describes in about 20 pages the geological profession, the working conditions and types of employment, the opportunities for women, the related fields of employment, beginning jobs, advancement and conditions of employ-

ment, post-war outlook in the profession and the qualifications and training, and makes suggestions about getting a start. It is attractively illustrated. It is specially valuable to advisers of young students, and, while written primarily from the employment point of view, it also gives those entering the profession a condensed and business-like summary of what they may expect.

The Twelfth Annual Field Conference of Pennsylvania Geologists was held under the joint auspices of the Pennsylvania State Geological Survey and the School of Mineral Industries of The Pennsylvania State College between May 30 and June 2, and was attended by more than 100 eastern geologists. On May 30, a field trip took place under the leadership of G. MARSHALL KAY to the Middle Ordovician Bellefonte chemical lime quarries. On June 1, a field trip was devoted to the examination of the Cambrian and Ordovician sections near State College under the leadership of PAUL D. KRYNINE. During this trip the possibilities of new, deeper potential oil zones in the lower part of the Paleozoic section were brought to the attention of the conference. On June 1 and 2, two field trips, one along the famous Horseshoe Curve near Altoona and the other between Altoona and Williamsburg, were held under the leadership of FRANK M. SWARTZ. These last trips showed the entire section from the Pennsylvanian to the Silurian. This field conference was mainly devoted to stratigraphy and sedimentation and more than 20,000 feet of strata were shown.

E. F. OSBORN has been appointed professor of geochemistry and head of the Department of Earth Sciences of the School of Mineral Industries of The Pennsylvania State College, effective August 1. The Department is divided into the following divisions: geology, headed by F. M. SWARTZ; mineralogy, headed by P. D. KRYNINE; geophysics, headed by S. J. PIRSON; geography, headed by E. W. MILLER; and meteorology, headed by H. NEUBERGER.

E. T. HECK, recently with the New York State Geological Survey, has been appointed to the position of chief geologist of the Quaker State Oil Refining Corporation, production department, and will be located in Bradford, Pennsylvania, after July 1, 1946.

C. A. MALOTT, professor of geology at Indiana University, was the principal speaker at the last meeting of the Indiana-Kentucky Geological Society at the Vendome Hotel, Evansville, Indiana, June 21. His subject was "Underground in the Limestone Country."

New officers of the Indiana-Kentucky Geological Society elected for the coming year are: president, C. W. HONESS, Gulf Refining Company, Evansville, Indiana; vice-president, J. ALBERT BROWN, Sohio Petroleum Company, Owensboro, Kentucky; secretary-treasurer, F. H. LATIMER, Sun Oil Company, Evansville, Indiana; and additional members of the executive committee, H. W. BODKIN and IRA VAN TUYL.

Captain S. RUSSEL (PAT) CASEY, JR., has returned after approximately 4 years of service in the United States Army to take a position as district geologist of the Texas Gulf Coast area for the Woodley Petroleum Company of Houston. Captain Casey enlisted in the Army in 1942. He went overseas with the 1884th Engineers and saw action in the Solomons; Angaur and Pelelieu of the Palau Group; Guam, M.I.; and Okinawa, R.I. He returned to the United States the first part of June after 2 years of service in the Asiatic-Pacific theater. During the Okinawa operation he served as Battalion Executive Officer.

The following are newly elected officers of the New Orleans Geological Society: President, ROBERT R. COPELAND, The California Company; vice-president, RICHARD L. DENHAM, Humble Oil and Refining Company; secretary-treasurer, PHILIP R. ALLIN, Gulf Refining Company, Harvey, Louisiana.

L. L. NETTLETON has become a partner in the firm of Gravity Meter Exploration Company and has moved to Houston. For the past 18 years, he has been in charge of gravity interpretations for Gulf Research and Development Company at Pittsburgh. In his new connection he also will have charge of interpretations and reporting of results of gravity surveys.

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DENVER 9, COLORADO

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Geologist and Engineer
3131 Zenobia Street
DENVER COLORADO

CALIFORNIA

H. W. BELL
Geologist and Engineer
Consultant in Oil, Gas, Mining
for
Development, Production, Appraisal
1136 Wild Rose Dr., Santa Rosa, Calif.

PAUL P. GOUDKOFF
Geologist
Geologic Correlation by Foraminifera and Mineral Grains
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and
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614 S. Hope St.
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RICHARD L. TRIPLETT
Core Drilling Contractor
PArkway 9925 1660 Virginia Road
Los Angeles 6, Calif.

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HARRY W. OBORNE
Geologist
304 Mining Exchange Bldg. 230 Park Ave.
Colorado Springs, Colo. New York, N.Y.
Main 5663 Murray Hill 9-3541

ILLINOIS

C. E. BREHM AND J. L. McMANAMY
Consulting Geologists
and Geophysicists
New Stumpp Building, Mt. Vernon, Illinois

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

COLORADO

ROCKY MOUNTAIN
ASSOCIATION OF PETROLEUM
GEOLOGISTS
DENVER, COLORADO

President - - - - - - - - J. W. Vanderwilt
Mining Geologist
Midland Savings Building
1st Vice-President - - - - - - C. A. Heiland
Heiland Research Corporation
2nd Vice-President - - - - Robert McMillan
Geophoto Services, Inc.
136 East Twentieth Ave.
Secretary-Treasurer - - - - - A. W. Cullen
1024 Continental Oil Building

Luncheons every Friday noon, Cosmopolitan Hotel. Evening dinner (6:15) and program (7:30) first Monday each month or by announcement, Cosmopolitan Hotel.

FLORIDA

SOUTHEASTERN
GEOLOGICAL SOCIETY
Box 841
TALLAHASSEE, FLORIDA

President - - - - - - - - - - - I. J. Reed
The California Company
Vice-President - - - - - - - - Walter B. Jones
Geological Survey of Alabama
Secretary-Treasurer - - - - - - H. A. Sellin
Magnolia Petroleum Company

Meetings will be announced. Visiting geologists and friends are welcome.

ILLINOIS

ILLINOIS
GEOLOGICAL SOCIETY

President - - - - - - - - - - Jack Hirsch
The Texas Company, Box 476, Mattoon

Vice-President - - - - - - - - E. E. Rehn
Sohio Petroleum Company
Box 537, Mt. Vernon

Secretary-Treasurer - - - - John B. Patton
Magnolia Petroleum Company
Box 535, Mt. Vernon

Meetings will be announced.

INDIANA-KENTUCKY

INDIANA-KENTUCKY
GEOLOGICAL SOCIETY
EVANSVILLE, INDIANA

President - - - - - - - - Charles W. Honess
Gulf Refining Company, Box 774

Vice-President - - - - - - - J. Albert Brown
Sohio Petroleum Co.
Owensboro, Kentucky

Secretary-Treasurer - - - - - - F. H. Latimer
Sun Oil Company
Evansville, Ind.

Meetings will be announced.

KANSAS

KANSAS
GEOLOGICAL SOCIETY
WICHITA, KANSAS

President - - - - - - Harold O. Smedley
Skelly Oil Company
Vice-President - - - - - - - Paul A. Harper
Cities Service Oil Company
Secretary-Treasurer - - - Francis E. Mettner
Transwestern Oil Company
605 Union National Bank Building

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka.

LOUISIANA

NEW ORLEANS
GEOLOGICAL SOCIETY
NEW ORLEANS, LOUISIANA

President - - - - - - - R. R. Copeland, Jr.
The California Company, 1818 Canal Bldg.

Vice-President and Program Chairman - - -
- - - - - - - - - - Richard L. Denham
Humble Oil and Refining Company
Secretary-Treasurer - - - - - Philip R. Allin
Gulf Refining Company, Harvey, La.

Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

President - - - - - - - - - T. H. Philpott
Carter Oil Company

Vice-President - - - - - - - Brame Womack
Sohio Petroleum Corporation

Secretary-Treasurer - - - - - - - J. Ed. Lytle
Union Producing Company

Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

President - - - - - - - - - - J. A. Moore
Union Sulphur Company

Vice-President - - - - - - - James M. Bugbee
Shell Oil Company, Inc.

Secretary - - - - - - - - - Lloyd D. Traupe
Ohio Oil Company

Treasurer - - - - - - - - - D. E. Newland
Magnolia Petroleum Company

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - - - - Rex P. Grant
Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing

Vice-President - - - - - - Richard H. Wolcott
Sohio Petroleum Company, Mt. Pleasant

Secretary-Treasurer - - - - Charles K. Clark
Pure Oil Company
402 2d Natl. Bank Bldg., Saginaw

Business Manager - - - Kenneth A. Gravelle
Gulf Refining Company, Box 811, Saginaw

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY
JACKSON, MISSISSIPPI

President - - - - - - - - Frederic F. Mellen
Mellen & Monsour
Box 2571, W. Jackson Sta.

Vice-President - - - - - - - - J. B. Wheeler
Stanolind Oil and Gas Company

Secretary-Treasurer - - - - - - H. L. Spyres
Skelly Oil Company

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - - - F. P. Schweers
The Texas Company, Box 539

Vice-President - - - - - - Paul L. Bartram
Phillips Petroleum Company

Secretary-Treasurer - - - - - - - Ben S. Curtis
Independent, Box 156

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - Gerald C. Maddox
Carter Oil Company

Vice-President - - - - - - - Harold J. Kleen
Skelly Oil Company

Secretary-Treasurer - - - - Frederick H. Kate
Shell Oil Company, Inc.

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second Wednesday, at 12:00 noon. Skirvin Hotel.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - - - - - Delbert F. Smith
Oklahoma Seismograph Company

Vice-President - - - - - - - Henry A. Campo
Atlantic Refining Company

Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company, Box 169

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - - - - John G. Bartram
Box 591, Stanolind Oil and Gas Co.

1st Vice-President - - - - - Russell S. Tarr
Independent, Beacon Building

2nd Vice-President - - - - - John C. Maher
U. S. Geological Survey

Secretary-Treasurer - - - - - - John R. Crain
Ashland Oil and Refining Company

Editor - - - - - - - - Robert F. Walters
Box 661, Gulf Oil Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Tuesday (October-May), Chamber of Commerce Building.

TEXAS

CORPUS CHRISTI GEOLOGICAL SOCIETY
CORPUS CHRISTI, TEXAS

President - - - - - - Robert D. Hendrickson
Tide Water Assoc. Oil Co., Box 1008

Vice-President - - - - - - W. E. Greenman
The Texas Company

Secretary-Treasurer - - - - - O. G. McClain
Southern Minerals Corp., 411 N. Broadway

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 P.M. Special night meetings, by announcement.

DALLAS GEOLOGICAL SOCIETY
DALLAS, TEXAS

President - - - - - - - - - John W. Clark
Magnolia Petroleum Company, Box 900

Vice-President - - - - - - Willis G. Meyer
DeGolyer and MacNaughton, Continental Building

Secretary-Treasurer - - - - - John M. Clayton
Seaboard Oil Company, 1400 Continental Building

Executive Committee - - - - Fred H. Wilcox
Magnolia Petroleum Company

Meetings: Monthly luncheons by announcement. Special night meetings by announcement.

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

President - - - - - - - - - D. R. Guinn
Cities Service Oil Company
Box 779

Vice-President - - - - - - T. H. Shelby, Jr.
Humble Oil and Refining Company

Secretary-Treasurer - - - - - George N. Ely
Continental Oil Company
Peoples Bank Building

Luncheons: Each week, Monday noon, Blackstone Hotel.

Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - John H. Wilson
Independent Exploration Company
2210 Ft. Worth National Bank Bldg.

Vice-President - - - - - - Edwin M. Rowser
The Texas Company, Box 1720

Secretary-Treasurer - - S. K. Van Steenbergh
Sinclair Prairie Oil Company
901 Fair Building

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - - - Shapleigh G. Gray
Consultant, 1713 Esperson Building

Vice-President - - - - - - Charles H. Sample
J. M. Huber Corporation

Secretary - - - - - - - - - A. F. Childers
Gulf Oil Corporation

Treasurer - - - - - - - - Wayne Z. Burkhead
Union Oil Company of California

Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - - - - Dolph S. Simic
Cities Service Oil Company

Vice-President - - - - - - Lynn L. Harden
Sinclair Prairie Oil Company

Secretary-Treasurer - - - - - - Turner Wynn
Stanolind Oil and Gas Company

Luncheons and evening programs will be announced.

SOUTH TEXAS GEOLOGICAL SOCIETY
SAN ANTONIO, TEXAS

President - - - - - - - - Thornton Davis
Peerless Oil and Gas Company
2023 Alamo National Building

Vice-President - - - - - - Marion J. Moore
Transwestern Oil Company, 1600 Milam Building

Secretary-Treasurer - - - - - Paul B. Hinyard
Shell Oil Company, Inc.
2000 Alamo National Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

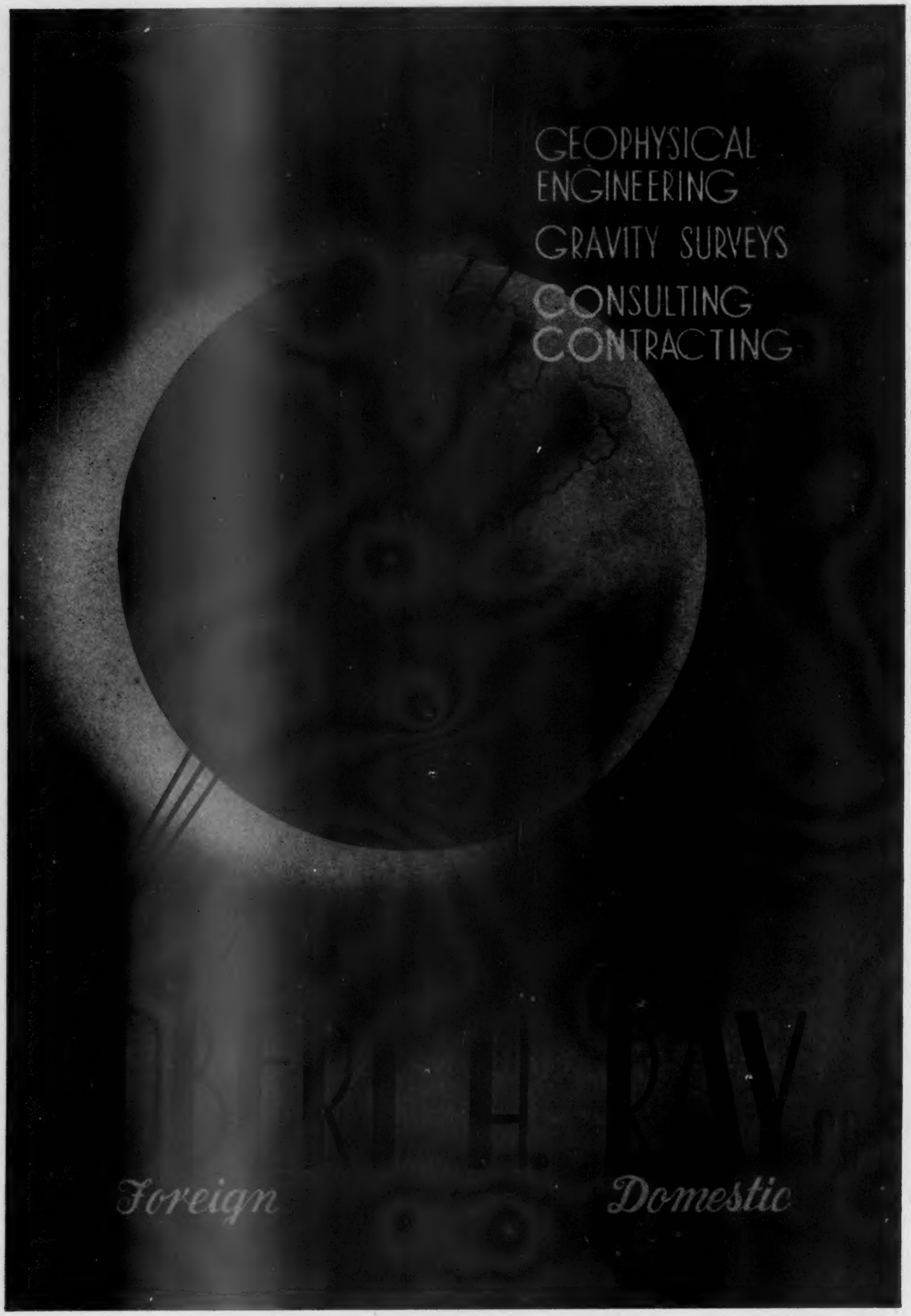
WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS

President - - - - - - - - - - B. A. Ray
Consulting, Box 1385

Vice-President - - - - - - - W. J. Hilseweck
Gulf Oil Corporation, Box 1150

Secretary-Treasurer - - - - Charles A. Shaw
Forest Oil Corporation, Box 366

Meetings will be announced.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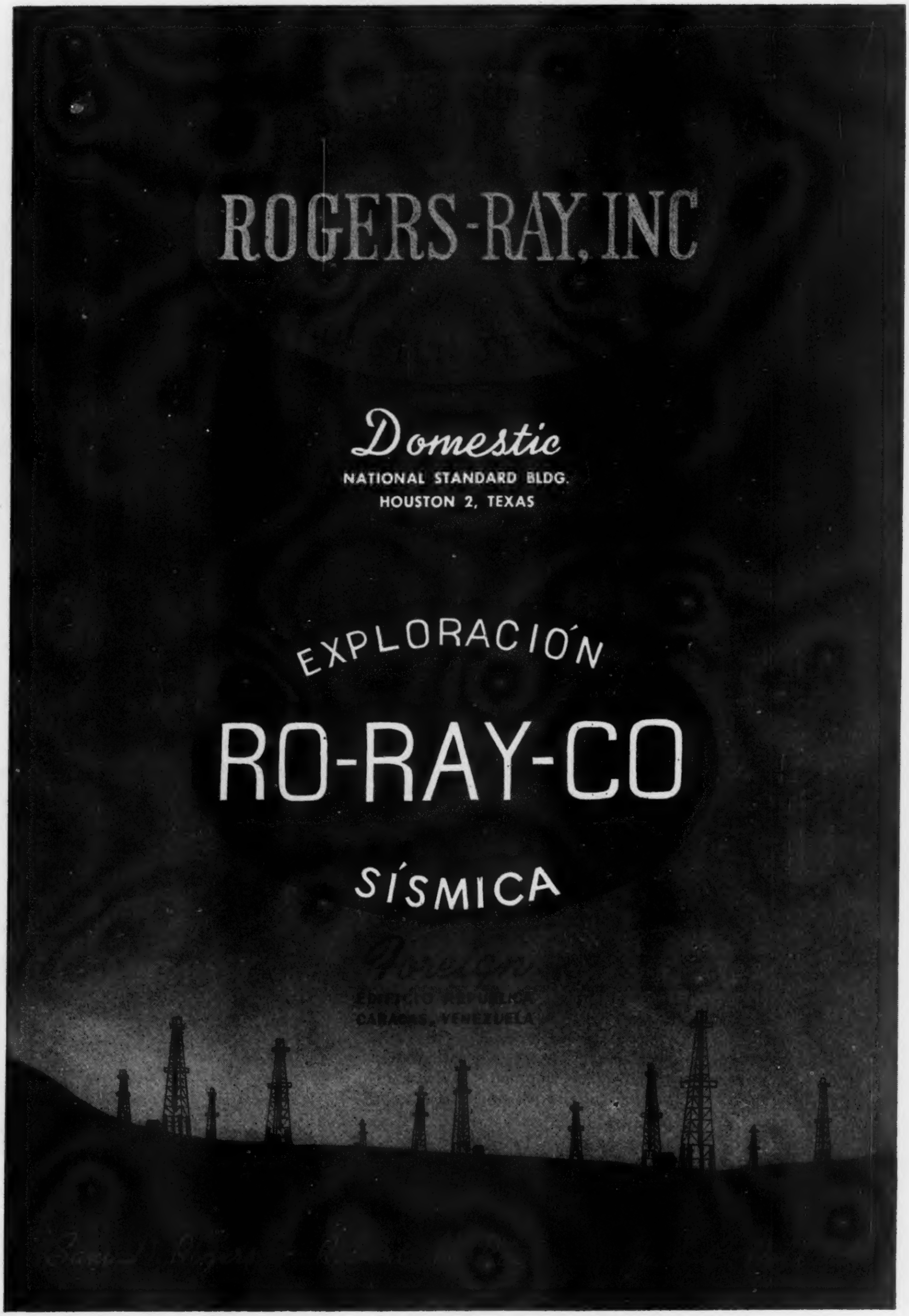
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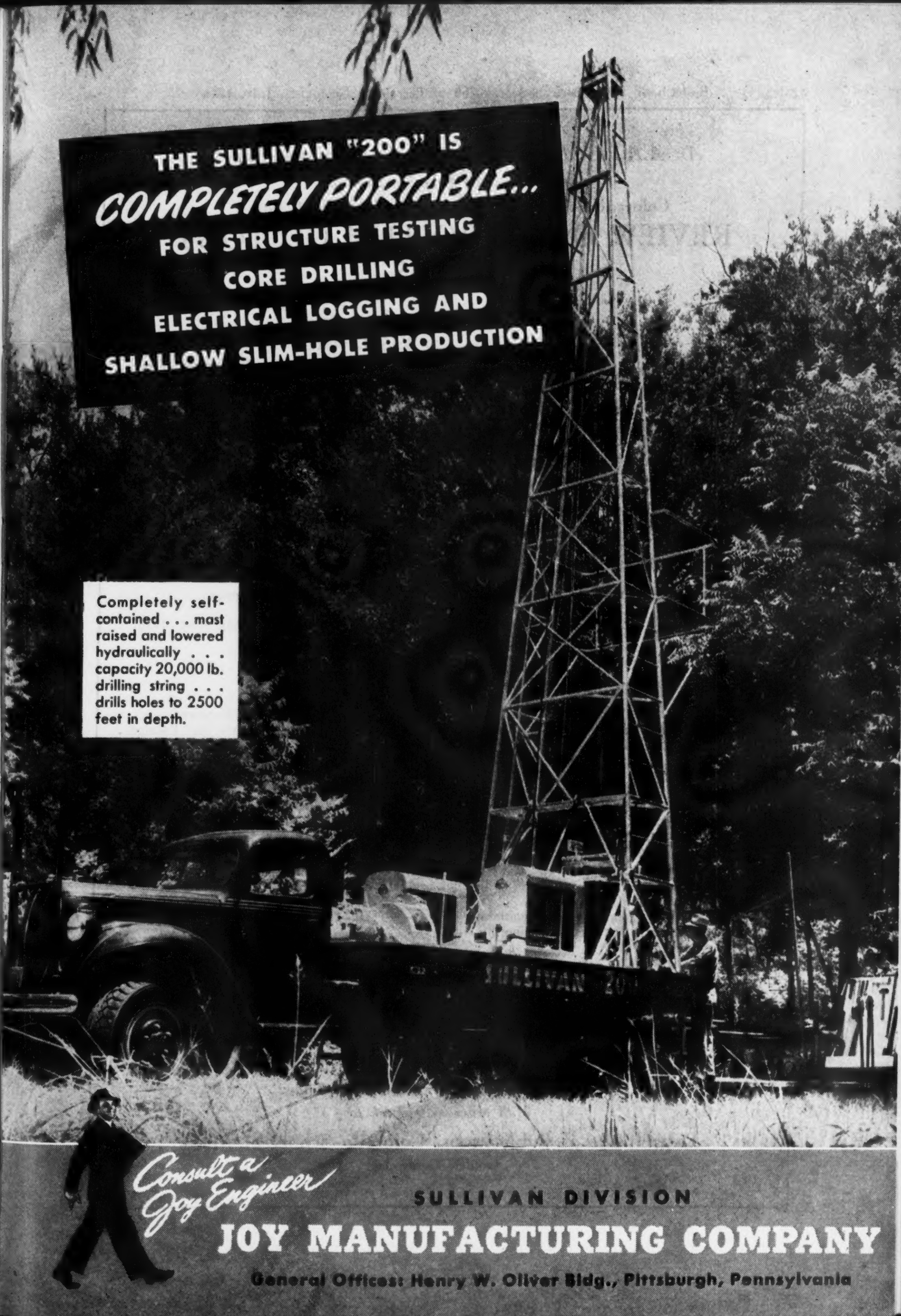
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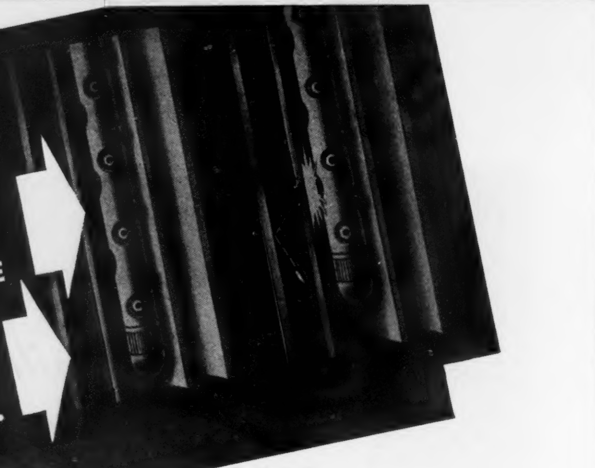

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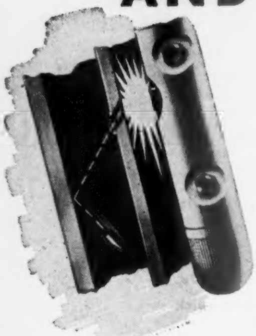

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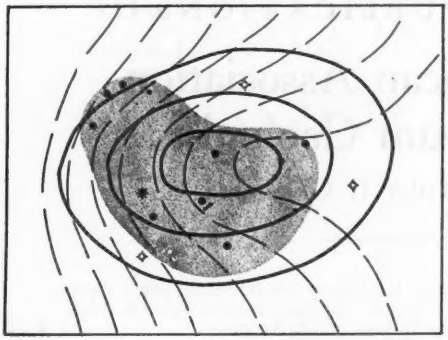


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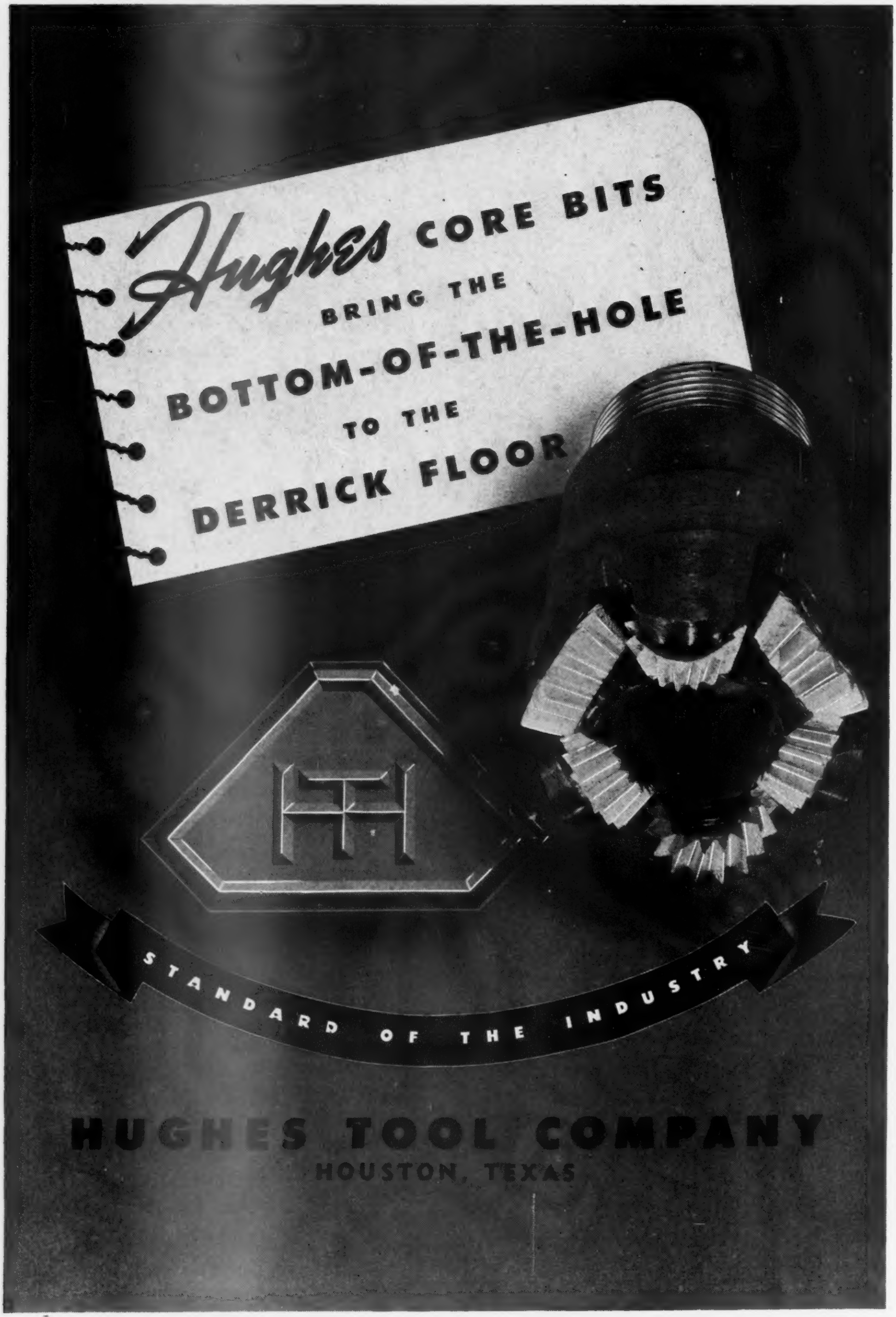

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